DIPOLES AND THEIR APPLICATION TO GRAPHIC ARTS

Abstract: Present pigments function as imperfect solid state devices to selectively absorb and reflect light. The need has existed for ideal pigments for 3 color reproduction as well as for other purposes. In terms of solid state devices and getting away from chemistry associated with pigments there is here presented a new concept for obtaining the ideal pigment. Dipole antenna theory which is applicable to television reception is also applicable on a reduced scale to affect visible light in the form of myriads of minute dipole particles each of which reacts with visible light the same way that a large scale antenna reacts with television signals. Control of color, reflectivity or absorptivity in sharp or wide spectral bands are now obtainable via this new concept. In addition, orientation provides polarization effects as well as control of reflectivity or absorptivity. All these effects are obtainable by varying the physical dimensions and orientation of dipolar particles. The material will provide non-fading, virtually indestructible colors. Only minute quantities of the same material are required for obtaining the entire gamut of characteristics. Applications to new printing inks, 3-D printed pictures are other fields in view.

In the graphic arts there has long been a need for pigments possessing certain ideal color characteristics which are required for better color reproduction.

Figure 1 shows three different color pigments employed in the graphic arts for color reproduction. These curves show percent reflectance versus wavelength. The real pigments are shown as the left hand curves which are the closest approximation the art has been able to achieve toward the desired ideal curves, which are shown as rectangles on the right hand curves.

The transmittance and reflectance curves of ordinary dyes and pigments are dependent upon chemical structure.

Ordinary pigments and dyes produce colors by the selective absorption and reflection of various wavelengths of light at the electronic level of the chemical molecules comprising the pigments and dyes.

Electrons go from one quantum state to another quantum state within the dye or pigment molecules. These effects are strongly wavelength dependent.

Stable chemical structures are relatively rare. Most chemical structures are relatively easily deteriorated by ultraviolet, visible and infrared light, heat and chemical action. After many years of research, chemical colorists have found only a relatively few stable dyes and pigments. These have fixed color responses and must be chosen and blended with great skill in order to achieve the desired end result.

A new approach was needed to enable the specification and engineering of color producing materials.

Light is an electromagnetic wave having three fundamental attributes, which are: amplitude or intensity; wavelength or color; and polarization or the vibration direction at right angles to the ray.

These three fundamental attributes of light are shown in Figure 2.

A half-wave dipole antenna, which is normally used for television reception, has interesting properties.

The half-wave dipole is capable of

controlling all three attributes of light, by varying its length, thickness, resistivity and angular position.

The electric power absorbed from the radiation by the half-wave dipole depends upon two orientation angles of the dipole. The first angle, θ, is that between the length of the dipole and the signal path. The second angle, $\emptyset$, is that between the length of the dipole and the direction of polarization of the signal.

Figure 3 shows a polar graph of radiant power absorbed versus angle θ.

In Figure 4 the radiation ray path is normal to the plane of the diagram, and there is shown the angle $\emptyset$ versus the power absorbed by the dipole.

A maximum response is obtained when the antenna is aligned parallel to the polarized electric vector of the radiation and at right angles to the signal path ($\emptyset = 0$, and $\theta = 90^{o}$). The antenna absorbs no power when it is placed at right angles to the polarized electric vector of the radiation; or arranged parallel to the ray path.

When adjusted for a maximum response, a half-wave or $\lambda/2$ antenna is then said to become resonant to the particular wavelength λ.

The power absorbed by the dipole from the radiant energy may be re-radiated, or absorbed and dissipated as heat, depending on the electrical resistance of the half-wave dipole antenna.

If power is to be absorbed from the dipole antenna and utilized in an outside electric circuit, as for example in a television set, a matched or characteristic resistance of 73 ohms must be inserted at its center of the half-wave dipole antenna, as shown in Figure 5.

An antenna may be made of such material, thickness and length as to achieve full power absorption, or total reflection.

In Figure 5 there is also shown a half-wave ($\lambda/2$) antenna 2, in which the central resistor is replaced with a single rod having a distributed resistance of approximately 80 ohms, which results in total absorption of radiation in the wavelength range λ.

Now, if instead of a half-wave antenna with a central resistor or an equivalent distributed resistance, a half-wave antenna of low resistance is employed, then the half-wave dipole antenna becomes reflective for the full wavelength. The radiant power may be said to be absorbed by the half-wave dipole and then re-radiated in all directions, with the intensity direction pattern shown in Figure 3. Thus the resistivity characteristics of the materials, together with the length and width controls the distributed resistance of the half-wave antenna. These factors may be adjusted so that the half-wave dipole antenna has high absorptivity or high reflectivity for incident radiation of a given wavelength band.

Figure 6 shows another very important property of the half-wave dipole antenna, the "effective cross section".

Figure 6 shows a half-wave dipole antenna having a thickness of (1/25) its length. Its length is $\lambda/2$ and its thickness $\lambda/50$. The physical cross section of this half-wave dipole at right angles to the light ray is:

$$(\lambda/2)(\lambda/50) = \lambda^2/100.$$

However, it is known that the effective cross section of a half-wave dipole antenna is much larger. The cross section from which the half-wave dipole appears to absorb power is approximately $\lambda^2/8$. A rectangle of this size is shown in dotted lines surrounding the antenna rod, the radiant power actually funnelling into the dipole. In this example the effective area of the antenna has been increased by a factor of $\lambda^2/100$ divided by $\lambda^2/8$ or 12.5 times.

Dipole antennas have been employed for the electro-magnetic spectrum all the way from long wave radio down through the television range into the microwave and millimeter wave spectrum.

We have observed dipoles which are resonant in the range of the wavelength of visible light. Yellow light at the peak sensitivity of the human eye has a wavelength of 0.565 microns (yellow). Elongated metal rods of submicron dimensions in colloidal suspension in a transparent plastic solution results in myriads of light responsive dipoles. The dissolved polymer in the solvent acts as a protective colloid to keep the dipoles in suspension.

The index of refraction n of a given medium may be defined as the ratio of the speed of light in free space, to the speed of light in the medium. Since the speed of light in all substances is less than in free space, n is always greater than 1. The wavelength of light in a given medium is inversely proportional to the index of refraction n of the medium.

Because the index of refraction of most plastics and solvents is approximately 1.5, the dimensions of a half-wave dipole must be decreased in inverse proportion; that is for n = 1.5 the actual resonant length of a half-wave dipole in such a medium becomes $(1/2)\lambda/1.5 = \lambda/3$.

For example, in a medium having an index of refraction of 1.5, a half-wave dipole should have a length of (0.565/3) = 0.188 microns of yellow light for 0.565 microns wavelength.

The $\lambda/3$ dimension, of course, is correct only for n = 1.5 and will vary with the index of refraction of the medium.

Another interesting property of the dipole is that the sharpness of its tuning, or the wavelength range over which it will absorb or reflect, depends on the ratio of the length to the thickness of the dipole; as well as on the resistivity of the dipole material.

Figure 7 refers to the reflection or absorption of radiant energy by a half-wave antenna showing the relative power absorbed or reradiated, versus the ratio of length to thickness of the antennae.

(A) For thin dipole antenna (25/1)

(B) For a thick dipole antenna (10/1)

We now come to the application of these basic concepts to light control; that is, control of all three basic attributes of light, intensity, color and polarization, by dipoles dispersed to form colloidal suspensions in plastic solutions.

Pigments formed from dipolar materials are virtually indestructable. The reflectivity or absorptivity characteristics of the colloidal dipole suspensions are predetermined by the appropriate selection of length, width and resistivity of the dipoles, together with their concentration and orientation.

Such a dipole suspension has the property of absorbing or reflecting specified wavelength ranges. Since a specific resonance characteristic is obtainable from the same material merely by changing its length to width ratio, very pure colors can be obtained by transmission or reflection from coatings formed from such suspensions.

The substances chosen to form the dipoles are chemically stable materials, which remain permanently within the suspension, and which are not subject to chemical destruction by ordinary atmospheric agents or by exposure to light.

The dipoles may be formed of metals such as gold, platinum, palladium, chromium, tin and the like, which are known to grow submicron crystal-whiskers, under appropriate conditions, usually from the vapor phase. Semi-metals such as carbon are also known to form crystal-whiskers. These crystal-whiskers may then be incorporated into a plastic solution to form a dipole suspension.

A crystal-whisker "pigment" made of a single substance of the utmost permanence, may be predetermined in its properties; a perfect black, a perfect white diffuse reflector, or pigments having sharp reflectivity bands in the yellow green, blue or other regions of the spectrum.

The effective cross section per particle in a medium of index of refraction n is $\lambda^2/8n^2$. In a film, for complete light absorption or reflection, and assuming no aggregation of particles, a suspension of submicron dipolar particles requires

$$(8n^2/\lambda^2) \cong 8 \times (1.5)^2/(.565 \times 10^{-4})^2$$

$$= 6.25 \times 10^9 \text{ particles/cm}^2.$$

Assuming a square cross section, the mass per particle is

$m_p = \delta\ (\lambda/2n)^3 b^2$ where b = width to length ratio and δ = density in gms/cm^3. For gold $\delta = 19$. Hence for $b = 1/25$, $m_p = 19\ (0.565 \times 10^{-4}/3)^3/25^2 = 2 \times 10^{-14}$ gms/particle.

The mass of dipoles per unit area, required to give complete coverage, ideally is:

$(\lambda/n)\delta b^2$ = (number of particles/cm^2) x (mass/particle) = $6.25 \times 10^9 \times 2 \times 10^{-14} = 1.25 \times 10^{-6}$ gms/cm^2.

Hence, very low concentrations of dipole particles, of the order of 2 micrograms/cm^2 are sufficient to provide effective surface coverage.

For a film of 10^{-3} cm (0.4 mil) thickness, and density = 1 gm/cm^2, this corresponds to a dipole concentration of only 0.125% of the solid film.

Because their effective cross section is much greater than the physical cross section, the dipolar particles may be very sparsely distributed in space. The dipolar particles are sufficiently far apart from each other so as to have no physical interreaction. Each dipolar particle acts independently of the other.

Figure 8 shows a film containing dipole particles with their length oriented normal to the surface. The film is transparent because the cross section particles present to the radiation is so small that substantially no light scatter and no light absorption occurs.

Figure 9 shows a film in the XY plane in which the dipole particles are aligned in the OX direction. Light transmitted along the Z axis into the surface emerges from the other side plane polarized with the electric vector E_y in the ZY plane. Reflected light is plane polarized with the electric vector E_x in the ZX plane. Reflected light is polarized and scattered.

Figure 10 shows a film having dipolar particles in random orientation. Reflected light is symmetrically scattered in all directions. The transmitted light and the reflected light show no polarization. However, since the dipoles are "tuned" to a particular wave band, the transmitted and reflected rays are complementary in color. Consequently, in the random orientation, the dipoles act as pigments. But however, these dipolar pigments are subject to control by variation of physical quantities of dimension resistivity and orientation.

Dipoles may be oriented by electric or magnetic fields and by viscous shear forces produced in the suspending fluid.

Dipole particles tend to disorient rapidly in suspending fluids of low viscosity. For low viscosity fluids the disorientation of dipolar particles may occur in milliseconds. The disorientation is due to Brownian movement or the random impact of the fluid molecules on the dipole particle.

However, if the suspending fluid viscosity is high, dipole orientation will persist for a longer time, from seconds to hours. A permanent orientation of dipolar particles may be achieved in a plastic solution by allowing the solvent to evaporate while maintaining the orientation.

Birefringence is the property of a material having different indices of refraction for light of different color (wavelength), and wave direction (polarization). This phenomena is shown, by transparent crystals, stressed glass, and stressed plastics such as cellophane.

Birefringent effects may be obtained by oriented dipoles which are transparent crystalline rods.

These effects may be achieved through the use of oriented dipoles. With dipolar birefringent materials, unique color characteristics may be obtained.

The dipolar concepts presented here have numerous important applications.

Dipoles tuned to different wave bands may be mixed in various proportions, so as to obtain specific color characteristics.

For example, in Figure 11, dipoles having three different lengths and three corresponding resonant peaks are intermixed to form a filter (A), and similarly dipoles having two other selected lengths are mixed to form filter (B) which has two resonant peaks intermediate to those of filter (A), (solid lines) to produce a filter (B), (dotted lines).

Filter (A) has peaks of absorption or reflection bands which lie between those of Filter (B). We have termed such filters "multichrome filters". These "A" and "B" multichrome filters are capable of mutually extinguishing light in a manner similar to that observed with polarized filters, but do not have the angular characteristics of polarizing filters.

Multichrome filters and complementary multichrome reflective pigments have important applications for 3-D printing inks, color separations, and other applications. Complementary white and black, or color pictures A and B may be obtained.

Black inks result from absorptive dipole particles having broad-banded response corresponding to a relatively thick antenna, or absorptive dipolar particles having a selected range of lengths. Utilizing dipoles having a similar broad-band response but high reflectivity, produces a white pigment, or ink.

A new type of ink having the property of polarizing light may be developed and used for 3-D printing applications. Alternatively, multichrome inks may be used for 3-D printing applications.

3-D printed pictures must be separately viewed by the right and left eyes. This may be accomplished by dipolar ink oriented in two directions of polarization 90° to each other, viewed by the observer through polarized lenses oriented at 90°; or, in the case of multichrome printing, via multichrome separation filters A and B.

A dipole film is useful in electro-photography for producing black and white or colored images.

Locallized orientation and disorientation of a dipolar surface coating is caused forming a permanent or temporary image in the coating. An electrostatic image is set up by the action of a light image, as in xerography; but without the dust particles.

A dipole film coating will provide a reproduction paper which is white when the dipolar particles are all aligned normal to the surface.

Pictures of printing on the surface are formed by locally disorienting the particles.

Another application of dipolar coatings is a carbonless copy paper for typewriters capable of producing an original and many copies.

In addition to the important applications of dipolar pigments in the graphic arts, they are useful in most other applications, for the dyeing of fabrics, surface paint, etc.

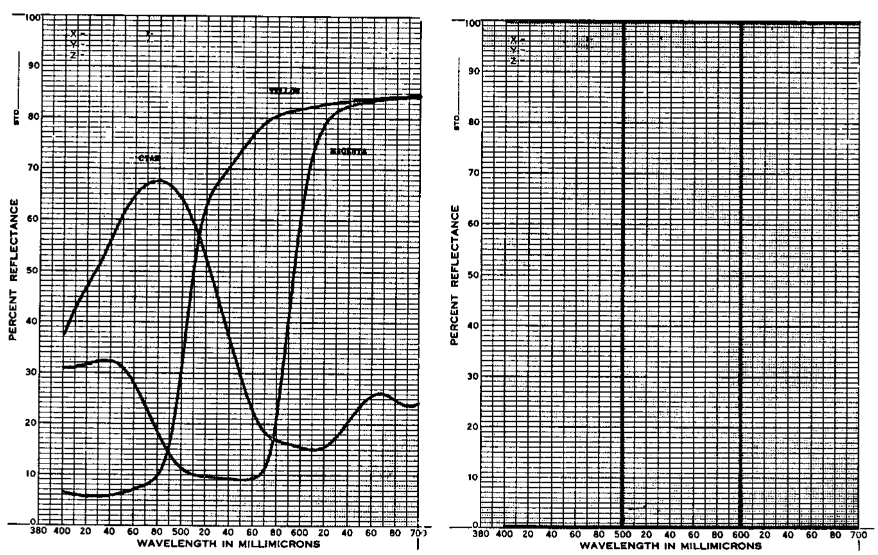

Figure 1. Real and ideal pigment colors.

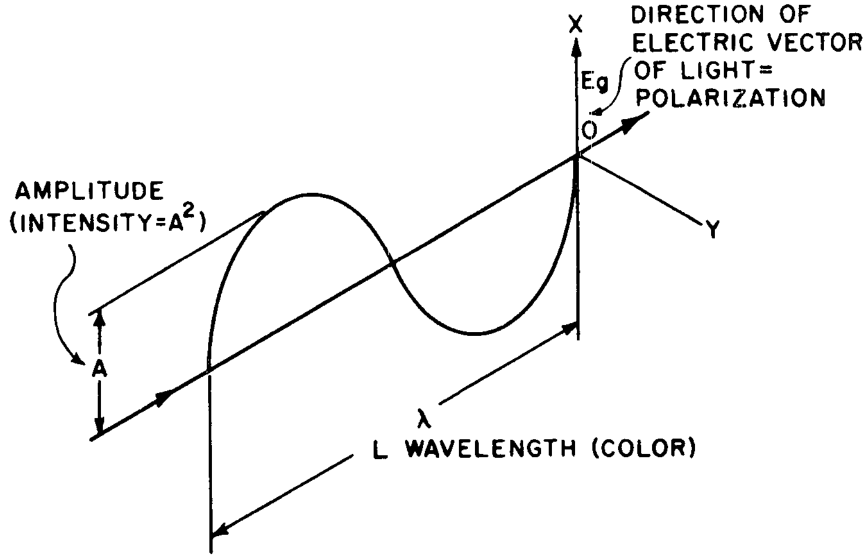

Figure 2. The three fundamental attributes of light are: amplitude, wavelength and polarization

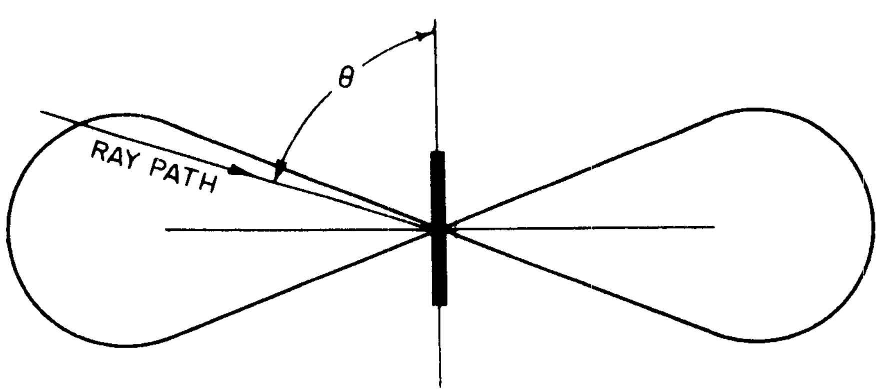

Figure 3. Polar graph of relative response versus angle of a dipole to a constant signal intensity.

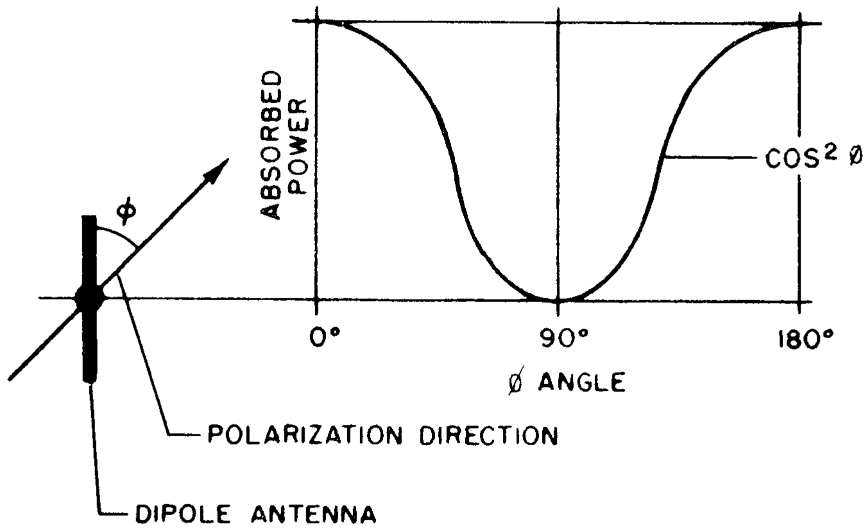

Figure 4. Relative response of a dipole antenna versus polarization direction φ.

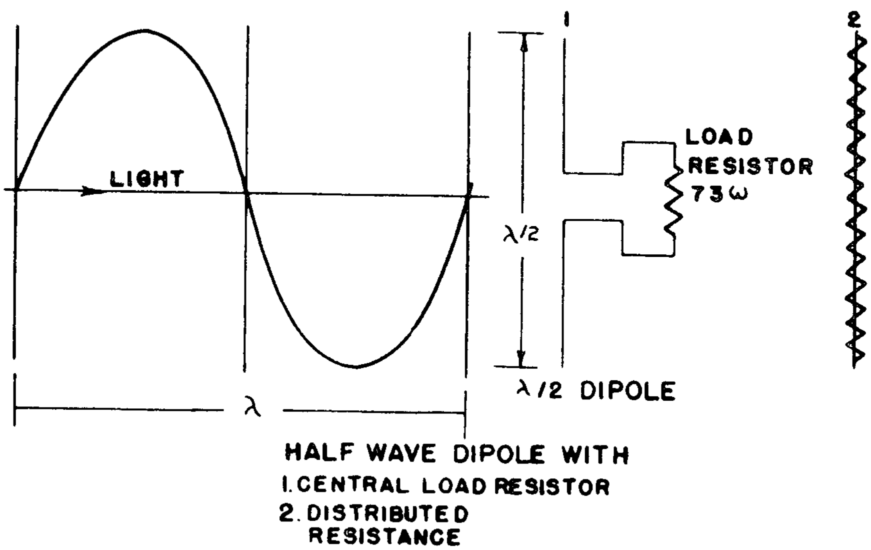

Figure 5. Showing half-wave dipole with characteristic load resistor tuned to absorb maximum power.

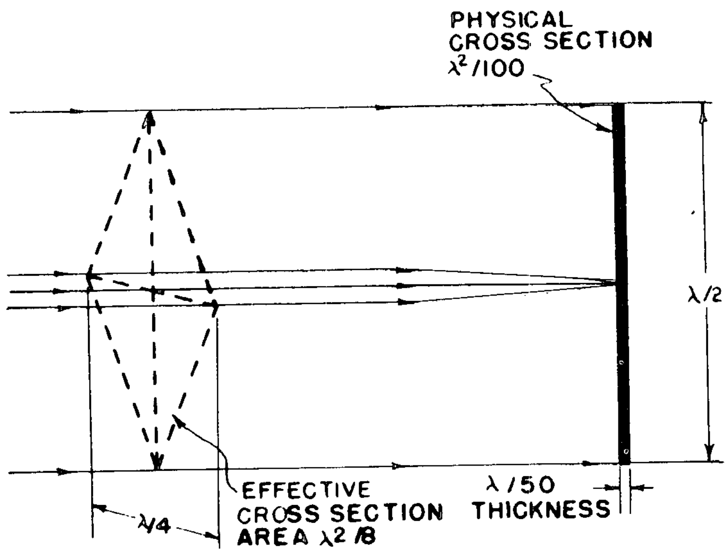

Figure 6. Showing that the effective cross section of an antennae may be many times the physical cross section; in this case 12.5X. Power is funnelled from an effective cross section into the smaller actual cross section of the antennae.

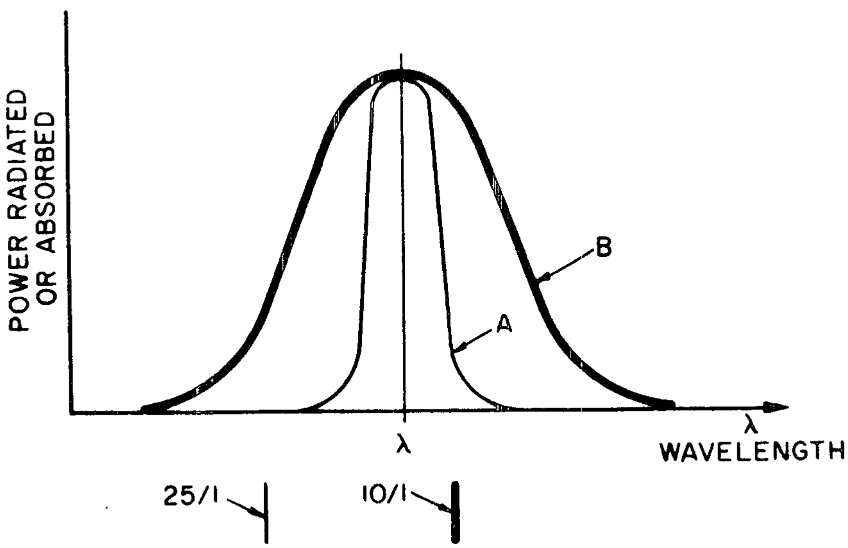

Figure 7. Showing the relative power absorbed or re-radiated versus wavelength for thick and thin half wave dipoles.

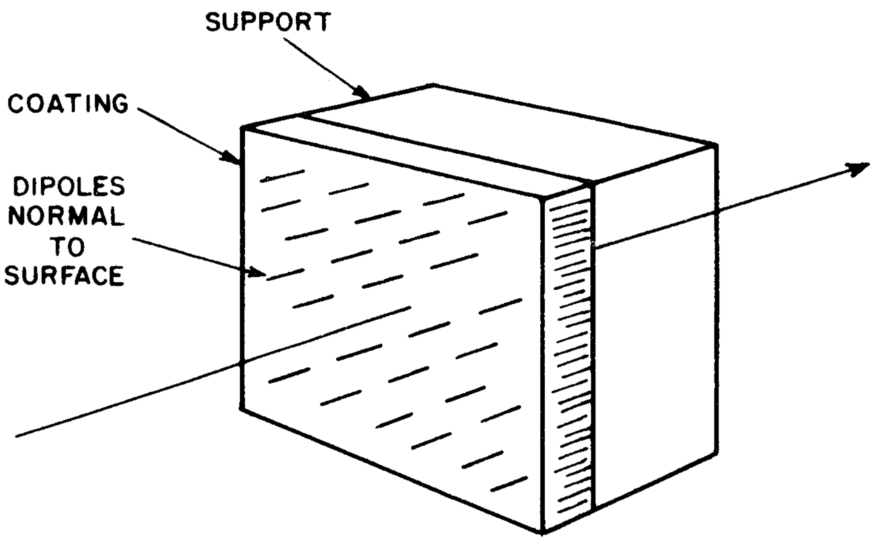

Figure 8. Particles aligned normal to the surface. Coating is transparent.

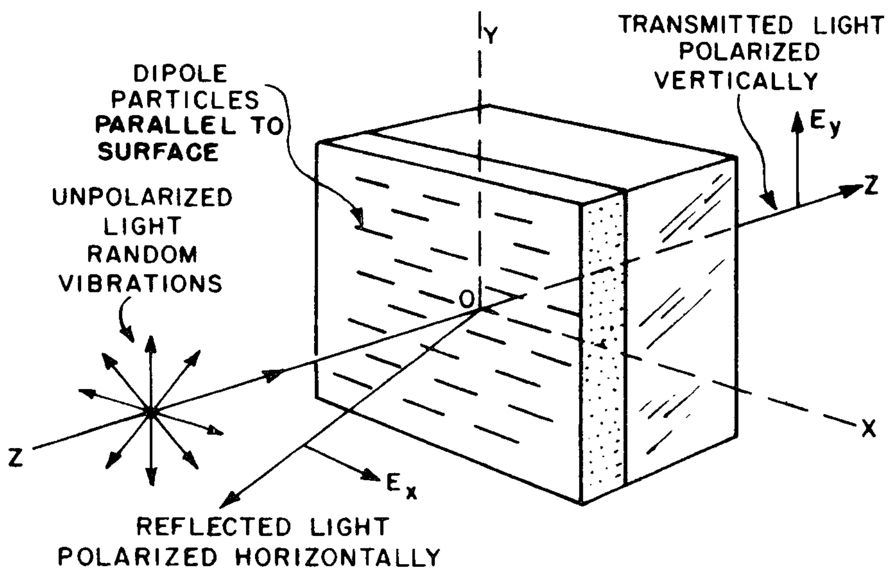

Figure 9. Shows the polarization effects of dipole particles oriented in the plane of the surface.

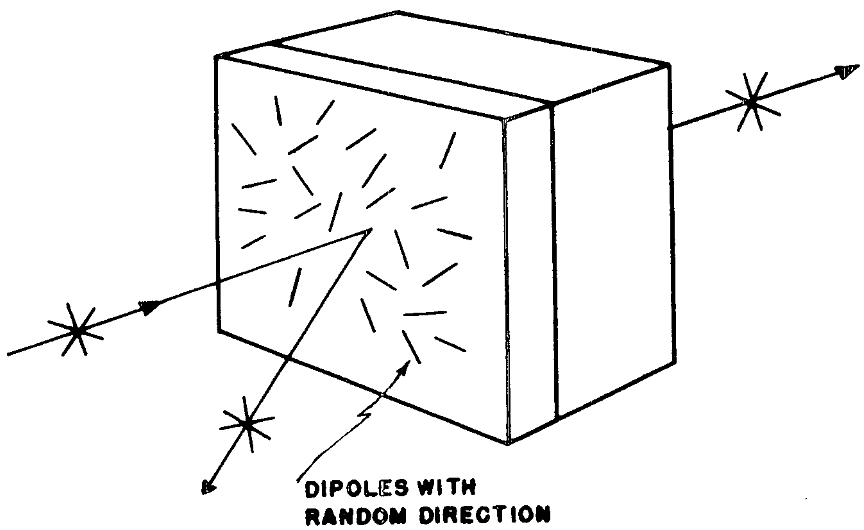

Figure 10. Showing dipoles having a random orientation.

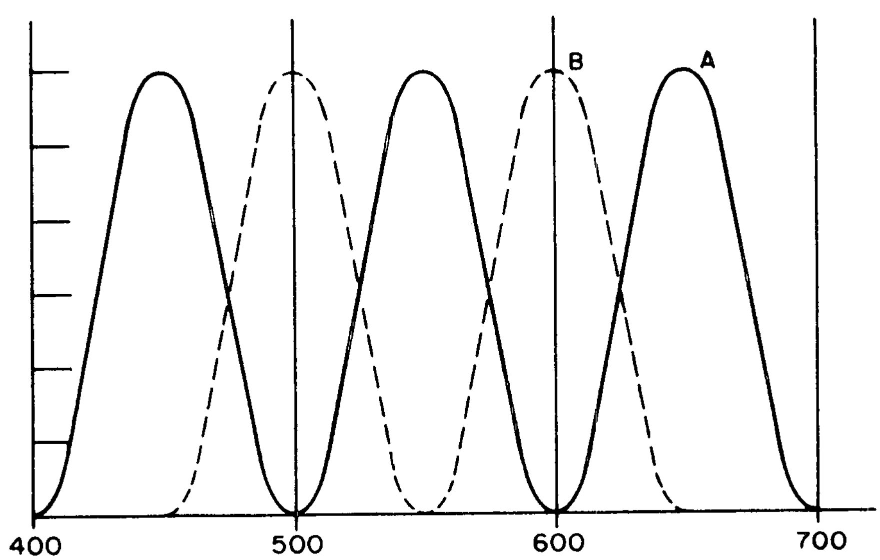

Figure 11. Showing complementary multichrome filters A and B produced by mixed dipoles of different lengths.

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A PROPOSAL FOR

IMAGE-INTENSIFIER SCREEN

By

STAT

19 March 1965

Proposal No. 9400-308-31

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LIST OF ILLUSTRATIONS

Approved For Release 2005/05/02 : CIA-RDP78B04770A002200060011-1

1.0 INTRODUCTION

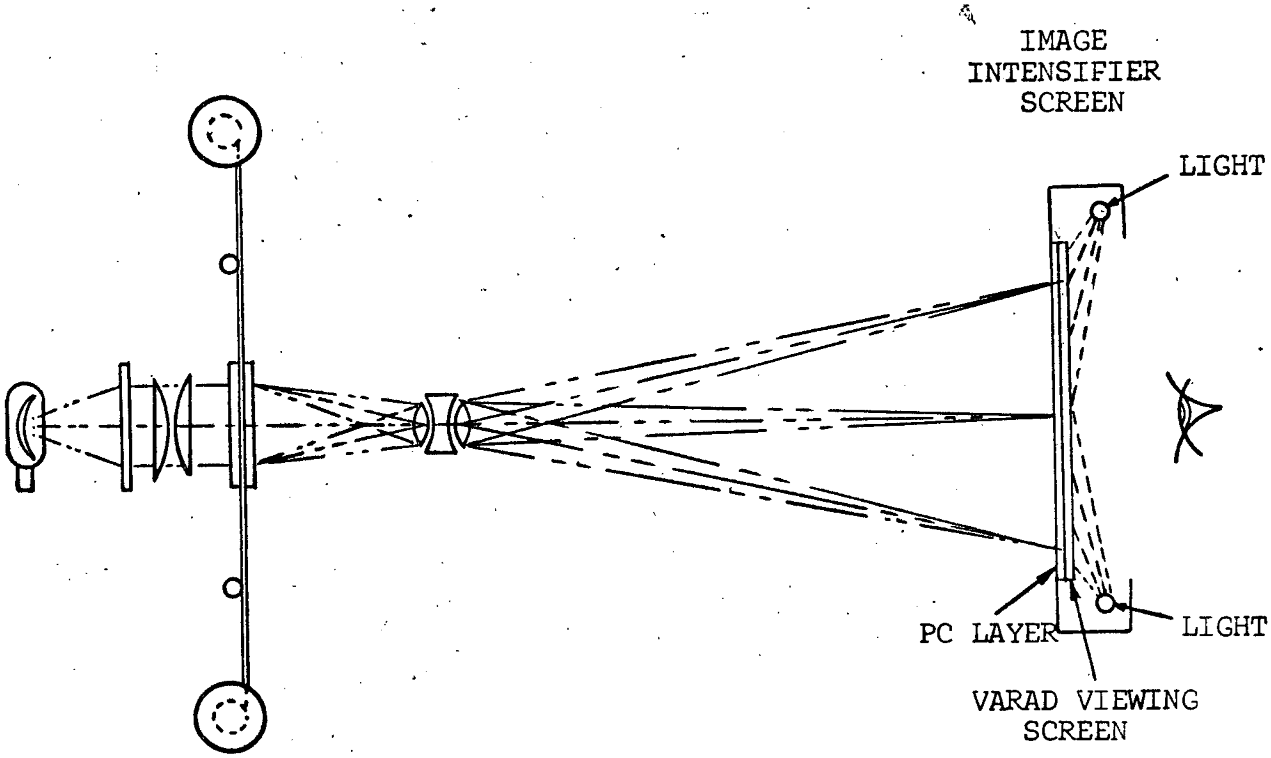
STAT [redacted] is pleased to submit this proposal for the development of a flat panel image intensifier screen (IIS). The system we propose is in full compliance with "Development Objectives" of 5 November 1964.

The system approach described herein is based on a new electro-optical display material, together with the application of advanced image intensifier techniques that will permit particularly advantageous utilization of the new material. The approach is an outgrowth of the intensive research and development program that has been STAT conducted [redacted] both with company funds and on Government contract work, in the fields of sophisticated display systems and photo-interpretation.

The new material, called VARAD, has the property of varying its transmittance, absorbence, or reflectance of radiation in response to an applied electric field. VARAD, employed to replace the function of electroluminescent (EL) material in an image intensifier screen, would lead to certain fundamental advantages not achievable in the conventional EL-PC light amplifier.

These advantages in an IIS, revealed by theoretical, experimental, STAT and system studies [redacted] include:

a. Effective optical density of "black velvet", with a maximum contrast ratio corresponding to a ratio of optical densities of 15, and maximum brightness far exceeding the present state-of-the-art capabilities of EL. This leads to image



VARAD PC SCREEN

Figure 1.1 Transparency is imaged on rear surface of Image Intensifier Screen, exciting photoconductive film. Light energy reflected from VARAD is many times greater than incident energy. Photo interpreter may examine magnified image on VARAD screen under normal ambient light.

contrast properties far superior to that achievable with EL materials. No deterioration of output layer lifetime as a function of high brightness.

b. No degradation of image contrast in high ambient light.

c. Wide-band excitation frequency response to electrical excitation. This permits optimum design for sensitivity to low light levels in the input image in terms of most effective utilization of the photoconductive (PC) material, impedance matching, and other considerations.

d. For a given brightness lower excitation voltage requirements than those of high performance EL materials; greater gain.

e. Much wider dynamic range than is possible with an EL layer.

f. Several exciting new possibilities for limited or extensive image manipulation when VARAD is used by itself or in conjunction with EL material; the degree of image manipulation achievable depending only on the degree of complexity allowed.

g. Substantial improvement in time constant should be achievable. Time constant build up limited only by photoconductive response time.

With respect to other performance characteristics, an IIS utilizing VARAD should be equal to or better than a conventional EL-PC configuration. These characteristics include linearity, resolution, signal/noise ratio, viewing angle, achievable size, life expectancy, power requirements, monochromatic sensitivity, cost, and size.

In many cases, one of which is indicated below, it is expected that because of the inherent design flexibility engineering trade-offs can be made to significantly improve many of these performance characteristics by using VARAD, beyond the requirements of the RFP.

It is anticipated that some of these additional performance characteristics can be improved through the increased design flexibility permitted by VARAD due to its wide bandwidth, or by the ? greater number of design parameters available on combining VARAD with an EL layer. An example of this might be linearity. Here, a design problem would be to utilize natural non-linearities to best advantage. Design considerations would involve thresholds that prevent excitation signals from showing up in an unwanted way in the image. On the other hand, non-linearities would be combined so as to achieve linearity and contrast control over the range desired, as far as possible, after reducing the non-linearities as appropriate, by solid state and chemical methods. As more design parameters become available, or as the allowed operating range becomes wider, more can be accomplished along these lines.

Unlike EL material, VARAD is not self-luminous, but, rather, is a modulator of light, being vastly more sensitive, and is a much thinner layer (1.5 mils at the present time) than a Kerr cell or ADP light switching arrangement.

VARAD, supplied [redacted] has been investigated extensively [redacted] [redacted] precisely for the light amplifier and IIS application area.

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Other applications of VARAD have been explored [redacted] but apparently not the IIS applications. The proposed program involves directed research and development, beyond the analysis and experimental results presented in this proposal; but we have carried the work far enough to be confident that the proposed approach offers much greater promise than an attempt to improve on the EL-PC approach. STAT

In addition to making use of the exceptional properties of VARAD, we propose to further develop the control-grid approach developed by

STAT [redacted]

Basically, our proposed IIS configuration will consist of substituting VARAD for the EL layer in a grid-controlled continuous layer panel. STAT The [redacted] grid-controlled PC layer eliminates the need for a grooved PC configuration that degrades resolution, obtaining high sensitivity without the grooves, and a resolution of 250 lines per inch. The use of VARAD in this arrangement should lead to even higher sensitivity, and eliminate other design problems. This is discussed in Section 2.

STAT [redacted] is staffed with an interdisciplinary group of scientists, systems analysts, solid state physicists, and engineers engaged in basic and applied research, system development, and production of instruments tailored to needs of the Government and industry, particularly in the image intensifier and display fields. This group combines the "know-how" required for the utilization of VARAD and other electro-optical materials in engineering applications with the background in display and IIS techniques and research and development that is essential in the system development phase of the program. In addition to notable achievements in the development of information processing systems, and in the IIS area, [redacted] has been credited with innovations and scientific accomplishments in the development of photochromic and video systems. STAT

The technical discussion and analysis of the proposed image intensifier screen is presented in Section 2. Section 2 includes a description of VARAD in some detail, as well as setting forth techniques for advantageously combining VARAD with PC material and other IIS componensts. The proposed work tasks and program schedules are then presented in Section 3. Section 4 outlines the [redacted] STAT STAT [redacted] rganization and Management structure, technical personnel, and pertinent scientific and engineering background and facilities information.

Utilizing VARAD, together with the [redacted] grid-controlled STAT PC layer an [redacted] proprietary techniques outlined in Section 2, and STAT taking advantage of such conventional design practices in light amplifier technology as may remain desirable in the new context of our proposed approach, it is the considered opinion of [redacted] that we STAT can more than satisfy the requirements of the RFP. We also believe that in performance of the proposed program, we can achieve a major breakthrough in the IIS field, in which VARAD will substantially replace EL material as the output layer for future IIS equipment.

VARAD is an obvious answer to this problem, and this application should, at this time, be pursued by a research group familiar with both the material and the application.

STAT In addition to [redacted] experience in various large screen displays, certain capabilities which are of particular usefulness in pursuing the IIS should be noted. In the course of improving the sensitivity of our large screen electrophotochromic STAT display system, [redacted] has developed a very similar technique to that proposed for the IIS.

This technique also involves the use of a liquid light modulator in thin film suspension, namely, a solution of organic spiropyran photochromic dye in a toluene solvent suspended in a glass cell with a thickness of liquid film of only .001". On this program, the liquid photochromics were utilized in such a fashion both to obtain high resolution, minimum molecular diffusion and the much higher sensitivity attendant to using photochromic dyes in liquid form. This development which was completed in the last two months has been quite successful and large screen display images impressed on the liquid photochromic film have been successfully demonstrated. In addition, a feature not required per se for the IIS but important in the construction of the IIS was developed; namely, a means of changing the fluid in this very thin film almost instantly upon demand.

Certain other optical thin film technologies have also become a matter of familiarity and knowledge of handling [redacted] STAT The extensive use of special anti-reflective optical coatings both multilayer dielectrics and single layer magnesium flouride coatings had to be applied to both plastics and mica for the first time known to us. This technology was instrumental in [redacted] STAT successful development of its present second generation electro-photochromic demonstrator which is being shown almost daily to people in the display industry. The use of anti-reflection coatings for the proposed system is of course important with regard to preventing unwanted reduction from the illuminated front surface of the IIS.

With regard to the opaque dielectric reflector utilized in the STAT proposed IIS, [redacted] has utilized these quite successfully and has again utilized these successfully on very thin film substrates. Such dielectric reflective layers were utilized in the form of so called "dichroic" reflectors deposited on both .001" thick mica sheets as well as on fiber optic plates. For the IIS such techniques are important because it is necessary to obtain reflection of light without using metallic reflectors which would tend to destroy the electric charge distribution which controls the transparency of the VARAD film which of course makes up the image to be viewed.

2.0 TECHNICAL DISCUSSION

The following section covers area by area, the technical considerations involved in the development of a VARAD/PC Image Intensifier.

Since the VARAD/PC approach can make use of all technology involved in the development of PC control structures for use with EL/PC Image intensifiers, the discussion will generally be related to work performed on EL/PC devices. Extrapolation to VARAD instead of EL is, straightforward since the inherent characteristics of VARAD are considerably less limited than EL.

2.1 Discussion of Requirements

The prime objective of the proposed development is to provide an Image Intensifier that will take a highly magnified dim image projected onto its rear surface from a photo transparency and provide on its front surface without degradation of an image of greatly increased brightness.

The development of high acuity cameras and photographic films of extreme resolution have increased the need for such an overall optical viewing system of high magnification, as an aid to photointerpretation. To obtain such magnification ratios directly, at brightness levels suitable for viewing under normal ambient lighting, requires projection light sources of sufficient intensity to cause physical damage to the film transparency, particularly at high film density levels.

The proposed unit will provide high brightness levels at the viewing screen with projection light sources of lower intensity. The viewplate is a two-dimensional VARAD "Light Amplifier," which by photoelectric control will reproduce electronically on its front surface an image projected on its rear surface, but at a greatly increased illumination level. The Image Intensifier will preserve the high resolution, dynamic range, and unity gamma associated with existing optical projection techniques. It is also capable of density expansion and compression, positive-negative viewing, optical contouring and other features which can greatly extend its usefulness.

It is a prime development objective to obtain a screen "package" which can be substituted for a diffusing glass screen in existing viewers, and in new viewers to be produced. The visible image on the viewplate is produced in a high efficiency VARAD screen. The light sensor on the rear surface is a continuous photoconductive layer followed by simulated electron multiplication. Power supplies and control panels can be remotely situated.

The following tabulation lists the design objectives which will guide the experimental and engineering effort on this program. Some of the objectives are presently available in image intensifiers while others will require intensive development. It is believed that the following list represents realistic goals which can be achieved during the course of the proposed program.

Gain?

Light output up to 200 foot-lamberts at magnifications up to 100X

Resolution of at least 10 lines/mm in both X- and Y-directions

Completely flicker-free display

Dynamic tonal range of 20 gray shades

Screen size of 12" x 12" capable of expansion to 30" x 30"

Signal-to-noise ratio greater than 100

Unity gamma over a range of brightness of 100X

Positive-negative viewing

Minimal energy transmitted through film to preclude film damage due to heating

Variable density compression and expansion

Life expectancy in thousands of hours

Usable with illumination from laser monochromatic light source

Rear projection

High rejection for incident ambient at viewing side

It is expected that the various design objectives will be achieved through dramatic improvement of the presently available devices.

The proposed approach is unique in that it substitutes a Varad cell for the EL portion of a EL/PC type Image Intensifier. This is advantageous for many reasons, but perhaps the prime consideration is that since Varad approaches an ideal circuit, it permits optimizing for photoconductor performance instead of having to compromise photoconductor performance to match EL characteristics. The other key consideration is that the Varad/PC Image Intensifier is really a high efficiency light modulator which uses an external light source. This permits independent control of the light output level while the cells inherent scattering and absorbtion when unexcited produces a true "black velvet" background even in high ambients.

Historically, since 1948, a great deal of effort has gone into the development of flat panel displays, with effort concentrated on photoconductive-electroluminescent panels until approximately 1960. Since then other means of driving electroluminescent panels have been investigated, such as travelling wave piezoelectric devices, crossed-grid electric field devices, ferromagnetic, and ferroelectric approaches.

It should be emphasized that this entire technology can be utilized in application to VARAD, and offers the chance for a quick breakthrough since VARAD is sensitive, flexible in driving requirements, and is a modulator of light rather than an emitter of light, thus to a large extent minimizing trade-offs previously necessary between speed of response, sensitivity, display brightness, and resolution.

Sensitivity for present day EL/PC light amplifiers is on the order of 0.01 foot candles or less, which is approximately 10^{-8} joules per cm^2 for a 1 second exposure.

To our knowledge the best resolution to date for a practical photoconductive controlled panel is that developed by STAT [redacted] The panel was shown at the N.Y. World's Fair where it demonstrated resolution of approximately 250 lines per inch. STAT [redacted] has studied this approach during the last year and is, therfore, in an excellent position to combine it with the use of VARAD.

Earlier continuous-layer EL/PC panels were made with a vapor-deposited PC layer and exhibited an undesirably low impedance. Our approach to solving this problem was to make PC layers of extremely fine powders bonded with transparent plastics. This increased the impedance but unfortunately resulted in reduced sensitivity to visible radiation. Another approach was the grooved panel developed by

STAT [redacted] which attempts to solve this problem by increasing the surface area and, therefore, the sensitivity, through the use of a grooved PC layer while retaining the desirable impedance characteristics of a relatively thick layer. The poor resolution of this device (1 to 2 lines/mm) is directly related to the grooving, and no major improvements seem likely in the near future.

Limitations of brightness, resolution, lifetime versus brightness, and sensitivity, as well as gamma transfer characteristics have been serious problems in the past; but not all of these limitations have been problems with all approaches. For example, resolution is the most serious limitation of the [redacted] grooved STAT PC layer approach, and is considered so serious as to rule out this approach for the proposed application; except as a possible supplimentary technique for alternative possibilities.

We believe that the grid controlled panels developed by STAT [redacted] offer the best approach because they use thin PC films permitted by their great sensitivity, but avoid the impedance problem by controlling the panel impedance with a fine wire AC driven grid, phase-referenced to the AC drive source.

The unique combination of this approach with VARAD further enhance the overall efficiency of the system.

The characteristics of the two phase [redacted] Image STAT Intensifier Screen are such as to provide a variety of controlled gamma characteristics. The gamma characteristics can be varied by adjusting the amplitude and phase of the control signal power supplies. Using these characteristics to best advantage will yield unity gamma over a 100:1 brightness variation or compression or expansion if desired.

2.2 The Proposed IIS configuration

The proposed image intensifier screen will consist of replacing the EL layer in a conventional EL/PC IIS with a VARAD cell and using a grid-controlled continuous photoconductive layer panel for control. Appropriate adjustment of parameters will be made to optimize the resulting configuration, as well as providing for suitable illumination of the VARAD. The substitution of VARAD for EL will result in greater brightness, and no resulting deterioration of lifetime. VARAD also will permit a time constant of as short as 0.01 seconds, contrasted with 0.06 seconds with EL material.

The manner of mating the fundamental input and output layers that we propose is illustrated schematically in Figure 2.1. Everything below the "opaque layer" in the figure is the same as in the [redacted] EL/PC system. With respect to electric fields, the geometry above the "opaque layer" is essentially the same as required for EL excitation except that a VARAD cell replaces the EL layer. The [redacted] PC portion, however, operates in the same fashion. See Section 2.4 for description of the [redacted] system.

The dielectric constant will not be the same for VARAD as for the EL layer, of course, and both layers in their respective configurations would consume small amounts of energy from the electric field, but this difference would not lead to significantly altered field strengths. The properties of VARAD in responding to the pattern of electric field strength, however, as contrasted to the properties of an EL layer in responding, should provide a

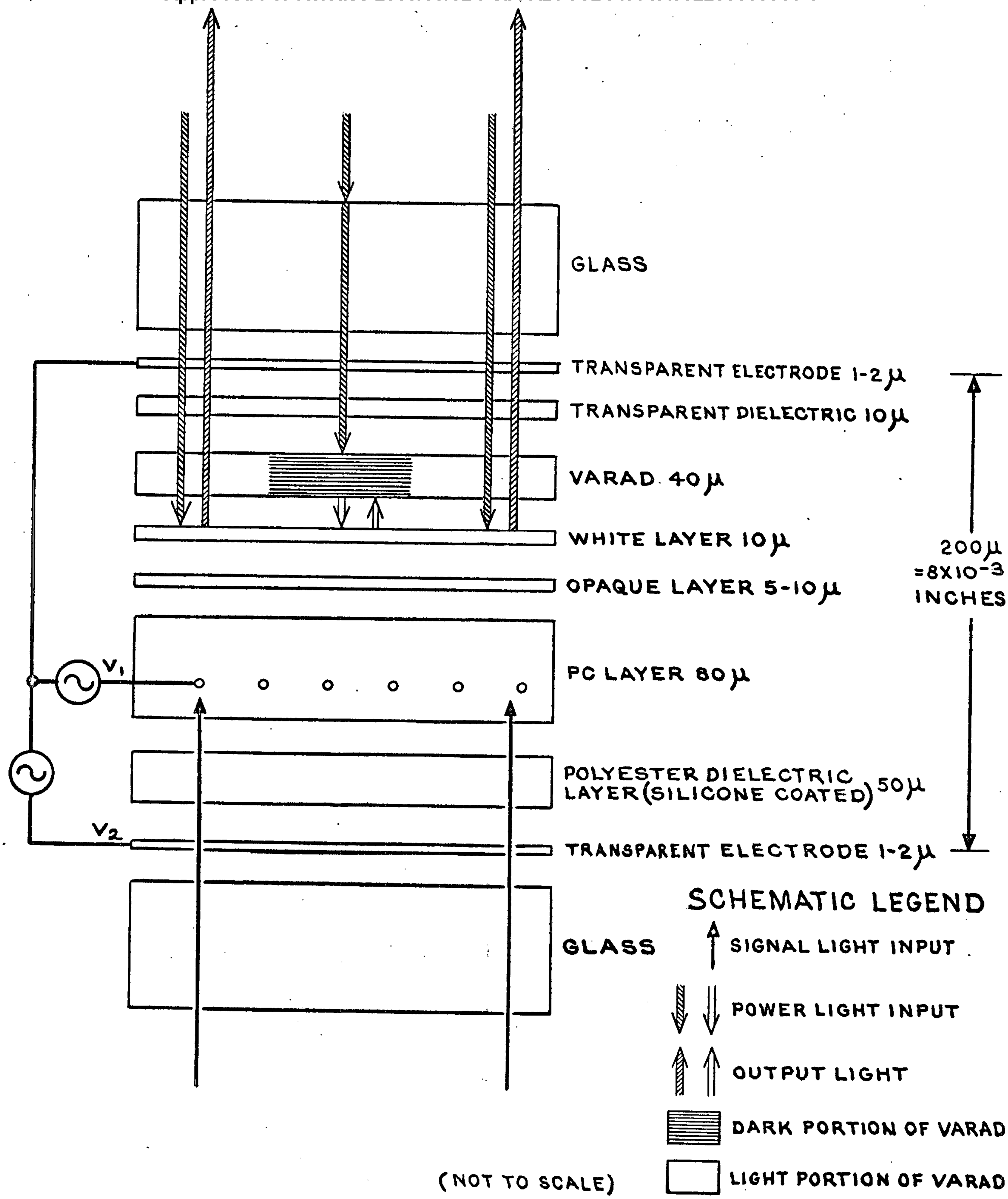

FIGURE 2.1: Exploded Schematic View of VARAD-PC Flat Panel 115

significant improvement in the system; this was mentioned in the INTRODUCTION and will be treated analytically in Section 2.6.

Thus, electrically, Figure 2.1 does not differ very much from the [redacted] EL/PC system, but optically, it is quite different above the opaque layer. As far as mechanical differences above the opaque layer in Figure 2.1 are concerned, large panels of Varad have already been fabricated and very narrow separation has been achieved for small panels.

STAT

Some development will be required to produce large panels with narrow Varad layers, but this should not present undue problems.

A white reflecting layer is used in the proposed system, but an electrically non-conducting dichroic mirror may also be useful as an alternate approach. The transparent dielectric above the Varad layer in Figure 2.1 prevents electrolysis of the Varad; the opaque and white layer below the Varad also performs this function.

Figure 2.2 illustrates how the configuration in Figure 2.1 would be front-lighted from the edge with the viewing light input. This light actually comes into the display panel at a shallow angle to the plane of the viewing surface, and then is viewed at a steeper angle (up to 45° maximum). The viewing light input illumination is shown coming only from one direction; but, actually, it would come from all four edges of the square or rectangular display frame, so as to provide roughly equal illumination at all points. Resulting resolution, evenness of illumination, and

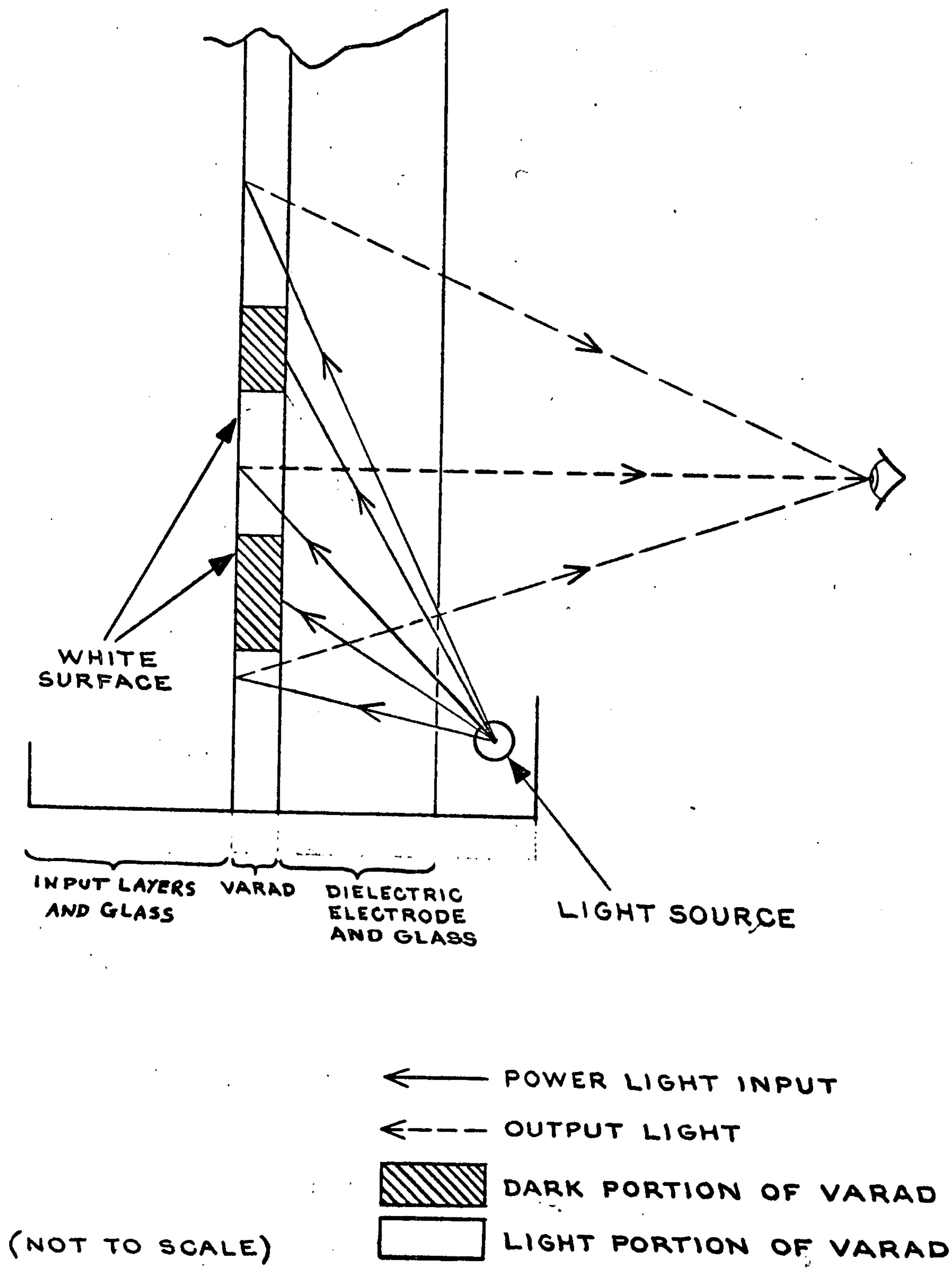

FIGURE 2.2 Method of Display Illumination

other optical as well as electrical considerations are considered quantitatively in Section 2.6 showing the improvement in many performance measures that can be obtained with the Varad system over the EL system.

Interference coatings may, of course, be added to the system in Figure 2.1 in order to minimize unwanted reflections.

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2.3 VARAD Properties

VARAD is a suspension in fluid of organic molecular or metallic dipoles "tuned" to optical frequencies (approximately 10^{14} cycles per second). In its normal state, VARAD appears very dark brown or black opaque, because the miniscule resonant dipoles scatter light in random directions until it is finally absorbed. When an electrical field strength of 10 to 100 kilovolts per centimeter (equivalent to 25 to 250 volts for a 1 mil layer) is applied in a direction parallel to the viewing angle, VARAD becomes clear. VARAD is thus an electronically controlled shutter with proportional control. In its present state of development, it opens in about 10 microseconds, and closes in 10 milliseconds.

Up to February, 1965, the thinnest cell that had been made was approximately 3 millimeters thick, and the largest area was on the order of a few feet square. Two VARAD panels, specially fabricated for [redacted] are approximately two inches on edge and contain a fluid layer only 0.0015 inches thick. This is the first time a VARAD cell has been made this thin.

The two panels are fabricated of glass that has been specially coated with first a transparent conductive film and secondly a protective dielectric film. Thus, each panel is a 2 electrode device with 2 wire leads. The two layers of dielectric film, and AC voltage excitation, are necessary to keep the VARAD from polarizing due to the migration of ions that would eventually drift to the electrode and counteract the electrostatic field. The AC voltage counteracts any such migration. Figure 2.3 is a schematic of the panels.

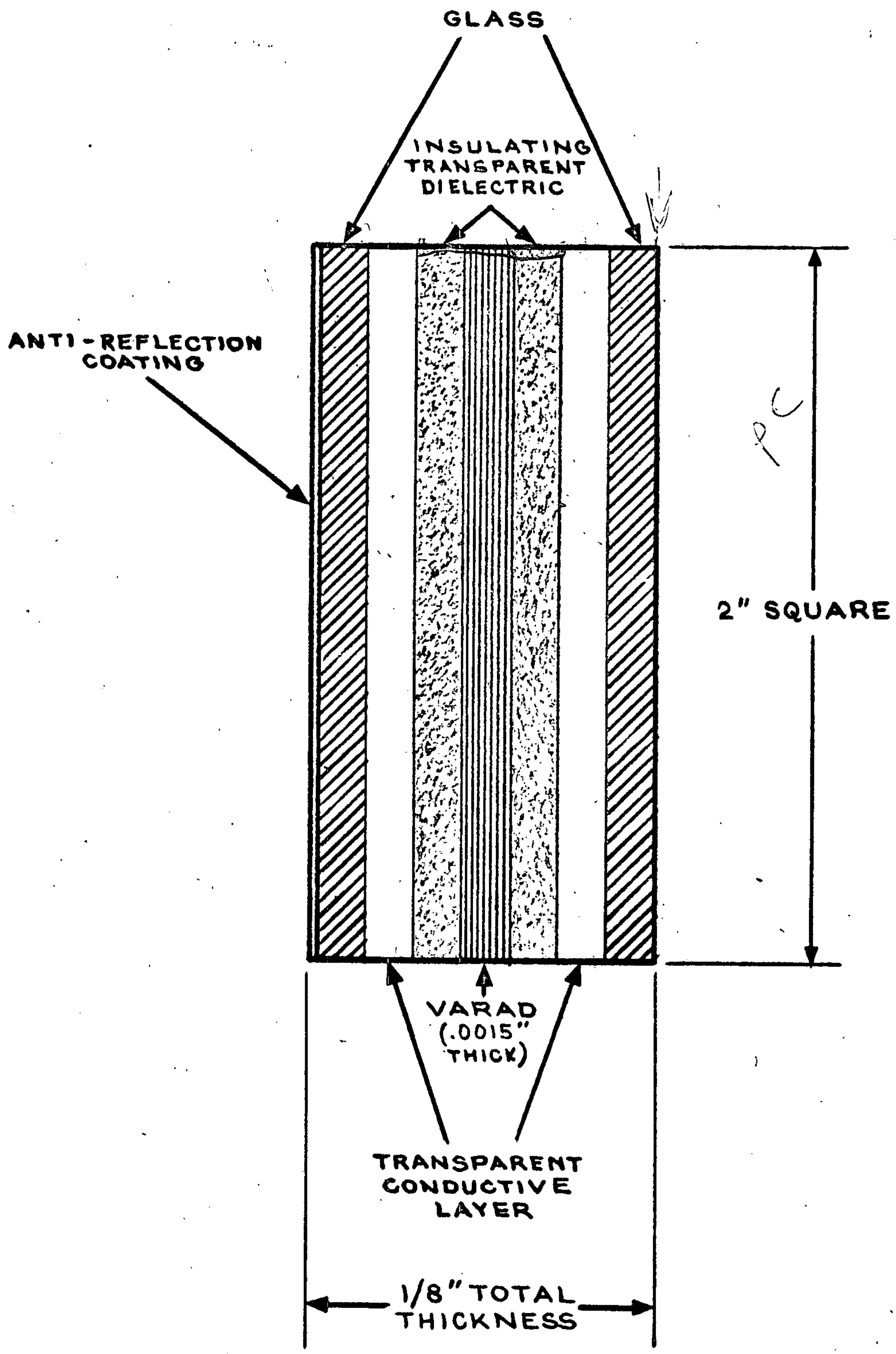

FIGURE 2.3 Schematic of VARAD Panel

The optical density for a single pass of light through the cells in their unactivated states is 2, or 99% absorbing, in the un-excited state. VARAD is a light modulator, unlike electrically excited phosphors. Thus, when its optical transmission is controlled by a PC light detector layer and the VARAD itself controls a strong "readout" light beam that is passed through the VARAD once, reflected by a white or mirror surface, and passed back through the VARAD a second time, a very sensitive high brightness display system is achieved. The use of a double pass of light through the VARAD squares the sensitivity of the VARAD optical transmission as a function of applied voltage.

Theoretically, photochromics could be used as light modulators for IIS applications if they were about six orders of magnitude more sensitive. Present day EL-PC light amplifier panels are approximately 10 million times more sensitive than photochromic materials. They are more sensitive because they use photoconductors as a valve for controlling an external source of electric energy instead of just passively responding to the image energy alone, as do photochromic materials. These EL-PC panels have a high power gain (100 might be typical) and the sensitivity is limited primarily by the dark current of the photoconductor. The overall power gain of a VARAD panel is much higher because VARAD itself is a second valve -- for light. When light is passed twice through a VARAD layer having an optical density of 2, the system has an effective optical density of 4. This "doubling" of the optical density would further increase the system gain.

Thin VARAD panels thus consist of the VARAD fluid contained between two glass layers, very thin transparent conducting and insulating layers being between the fluid and the glass plates. The dipoles are submicroscopic (roughly 1 micron long) needle-like particles that interact with light. The VARAD panel becomes light transmissive when an electric field is applied between the transparent conductors. This causes the dipoles to align at right angles to the glass plates, so that the dipoles are more or less parallel with the light rays. Upon removal of the electric field, the directions of the needle-like particles randomize as a result of thermal molecular impacts. Dipoles in random directions absorb or reflect light.

By choosing the size and shape of the dipoles, VARAD can be made to act as a very selective color filter under certain circumstances, or to appear quite black by reflected light when the layer is not in an electric field.

According to the manufacturer, the shelf life of VARAD should be indefinitely long, and no noticeable deterioration of the material has been noticed [redacted] when cycling it electrically or by subjecting it to high intensity light. The material may however be degraded if excess voltage is inadvertently applied.

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The resistivity of a VARAD panel, due primarily to the insulating layers, is very high, of the order of 1000 megohms, so that its electrical impedance is mainly capacitive. For instance, a cell 4 inches square and 3 millimeters thick, has a capacitance of 300 micro-micro-farads.

The applied electric field for controlling VARAD is parallel to the general viewing direction instead of perpendicular to it as in the case of a Kerr cell, and no optical polarizing layers are needed as in the case of the Kerr cell, APD, or KDP optical valves.

Between 100-200 volts will be sufficient for controlling the VARAD for the proposed application, whereas tens of thousands of volts would be needed to modulate a Kerr cell of equivalent viewing area, or several thousand volts for the ADP arrangement. For comparison, 100 to 1000 volts are needed to produce EL luminosity of maximum brightness. Voltage in the range of 100 to 200 volts for activating the VARAD liquid can be directly controlled by state-of-the-art photoconductive materials which would be put in an image plane similar to that previously utilized in EL-PC light amplifying panels.

Compared to EL layers, VARAD operates over a large frequency range up to at least 20 kc, whereas EL phosphors are usually impractical at frequencies above 1 kc. Also, EL layers normally require about 0.4 kc as a minimum for high light levels, although of course, the familiar EL night lights operate on 60 cycle AC voltage at very low light levels. Theoretically, VARAD could operate all the way down to DC if a fluid could be found that would not polarize. This wider frequency choice property of VARAD, as compared with EL material, allows much greater flexibility in matching VARAD to its image-controlling component such as a photoconductor, in terms of impedance.

The spectral characteristics of the VARAD IIS can be tailored to any desired portion, wide or narrow, of the IR, visible, or UV spectrum.

The VARAD panel requires very low power, since it is substantially a capacitive load, with a very high resistance photoconductor (approximately 10^7 ohms) causing the only power dissipation.

With a 10 cm x 10 cm VARAD cell, an electrodichroic ratio of 15 has been obtained at an applied frequency of 20 kc, the electrodichroic ratio being defined as the ratio of the optical density closed to the optical density open.

For an electrodichroic ratio of 15, upper and lower ranges of transmittance of

63%	(D = 0.2)	open
0.1%	(D = 3)	closed

or

50%	(D = 0.3)	open
0.0013%	(D = 4.5)	closed

or

31.5%	(D = 0.5)	open
1.3×10^{-5}%	(D = 7.5)	closed

has already been achieved, according to the vendor.

The opening (or clearing) time is 10 microseconds with an applied voltage pulse. To induce closing (darkening), the normal VARAD panel depends upon Brownian motion for which closure time is of the order of 10 milliseconds. Faster closing times can be induced by the application of a crossed electric field. Slower closing times can be obtained with higher viscosity fluid, which is the case for the thin 1 mil layers we have received.

VARAD panels are presently available up to 24 inches on a side. Larger sizes are available on special order.

In the panels presently utilized, very low concentrations of dipole particles are adequate. The order of 2 micrograms per cm^2 are capable of producing the results described above.

STAT [redacted] is apparently the first to have a thin layer VARAD cell, since the vendor has never fabricated one before, and the material is only a few months old. VARAD has apparently not been explored for display purposes by the vendor, and, as of this date, probably not by others. It is a material conceived in crude form by the manufacturer and perfected with Navy funds for flash blindness prevention and similar applications.

STAT [redacted] has developed an optical system and "know-how" for multiplying absorption effects and thus greatly increasing sensitivity. This application was developed by STAT [redacted] for the photochromic display systems but it is also applicable to VARAD.

2.4 Control-Grid PC Approach

STAT The [redacted] control-grid photoconductive panels use thin PC films. They have great sensitivity, and control the panel impedence with a fine wire AC driven grid, phase-referenced to an AC drive source (See Figure 2.4). The grid permits direct control of gain, sensitivity, and type of imaging. The [redacted] system, STAT illustrated in Figure 2.4 , uses al EL layer, where we propose to use VARAD. In other sections in this proposal we are interested in that portion of Figure 2.4 , below the "reflection layer". We will, however, continue to describe the entire [redacted] STAT Control-Grid approach in this section.

In addition to the unique control features inherent in the STAT [redacted] approach, the gist of their approach is this: they obtain use of lateral PC conductivity (large area activated-thin layer) by using a grid feed, whereas such systems as the RCA grooved panel approach use the surface of wedges to obtain the same effect. However the grid system does not limit resolution to the grid spacing, whereas the grooved approach does.

In Figure 2.5, drive and control signals are at the same frequency; by varying their relative amplitude and phase the following effects can be achieved:

Gamma Variation over the range -2 to +2

Positive Imaging

Negative Imaging

Mixed Positive and Negative Imaging

Gain Control Over the range from 0 to 100

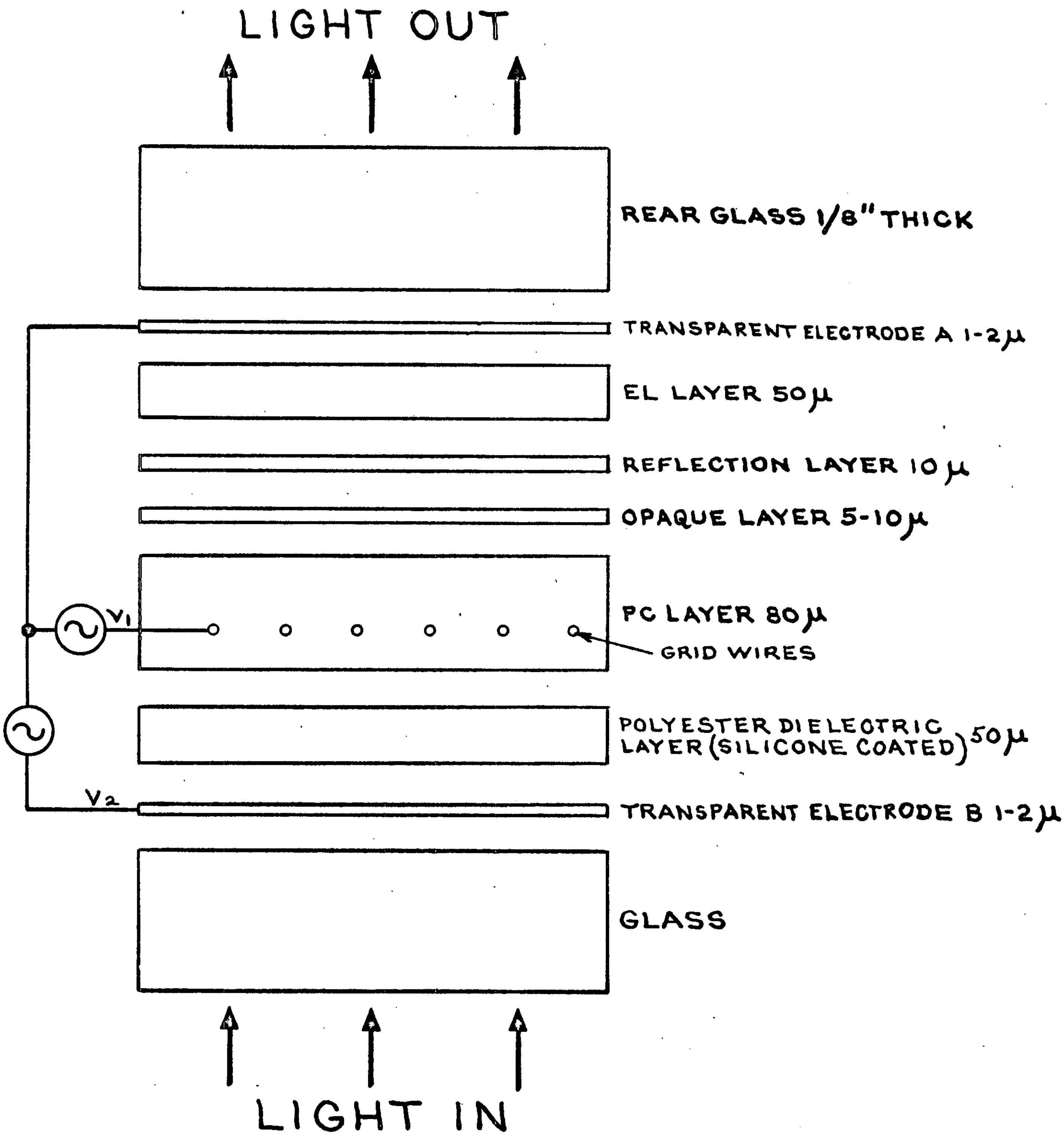

FIGURE 2.4

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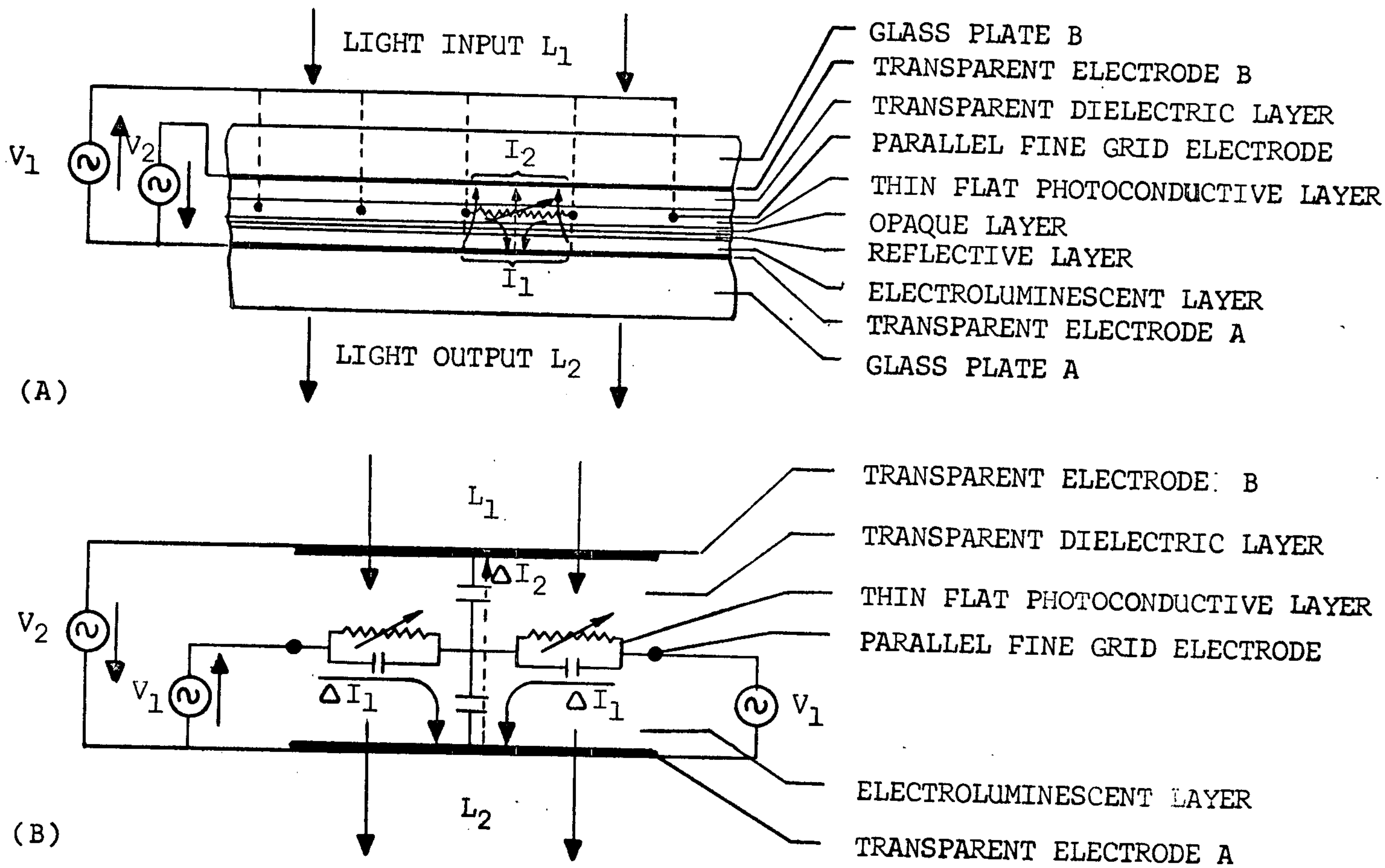


Figure 2.5 EL-PC Light Amplifier

The panels can be made to have a dynamic range in excess of 100 to 1 at a gamma of unity. Their demonstrated resolution is greater than 10 lines/mm, an order of magnitude better than that achieved with any comparable device.

A cross-section of an experimental model of the [redacted] STAT light amplifying panel and its power supply connections is shown in Figure 2.5. This structure, with its photoconductive layer sandwiched between an electroluminescent layer and transparent dielectric layer, is similar to a dielectric panel triode.

The operating power comes from two AC driving voltages of the same frequency but adjustable phase. A voltage V_1 is applied between the transparent electrode A and the grid electrode. A voltage V_2 is applied between transparent electrodes A and B. The photoconductive layer is excited by the light input L_1 that passes through the glass plate and the transparent electrode A.

Light output L_2 is proportional to the current flowing through the electroluminescent layer. Lateral photoconductive current through the photoconductive layer from the grid electrode is dependent upon light input L_1.

The use of lateral photoconductivity results in a low concentration of photoconductive currents, which enables resolutions higher than might otherwise be expected from the nominal spacing of the fine, parallel-grid electrode.

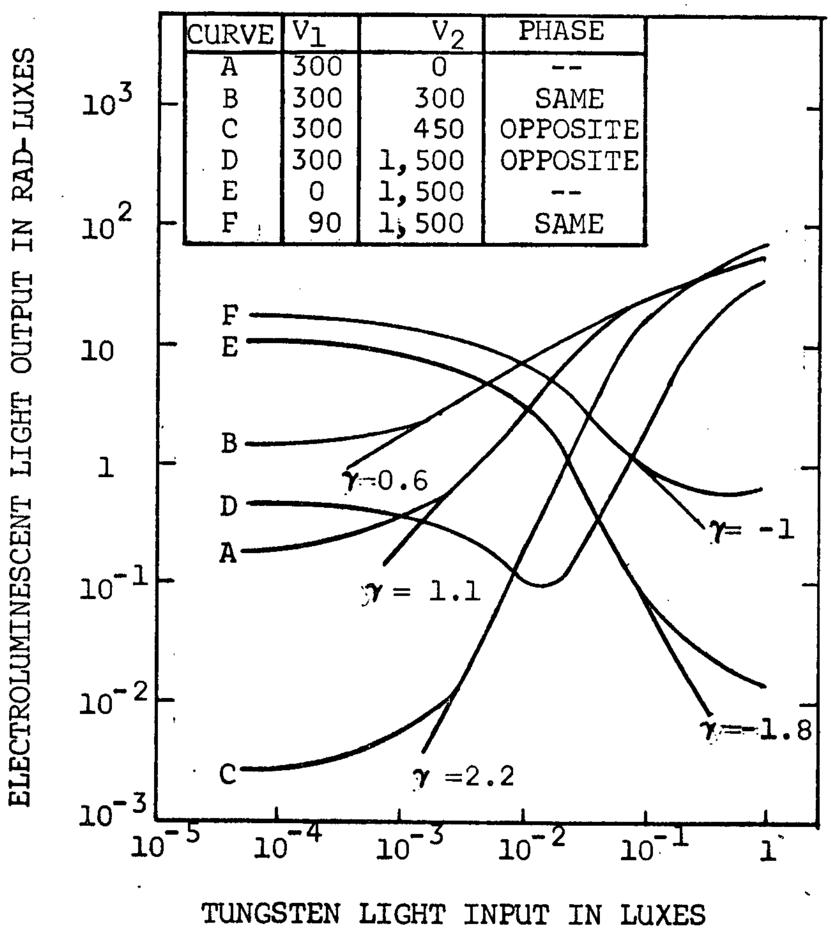
Light output is proportional to the amplitude of the vector current $I_3 = I_1 \pm I_2$, as shown in detail A of Figure 2.5. Current I_1 is the lateral photoconductive current varied by light input L_1; I_2 is the vertical capacitive current through the photoconductive layer. The amplitude of I_3 and light output L_2 can be made to increase, decrease, or exhibit a V shaped characteristic with increase in light input L_1, by adjustment of amplitude and phase relationship between V_1 and V_2.

Detail B of Figure 2.5 shows the simplest equivalent circuit diagram of the light amplification panel.

The input image can be intensified and converted to a positive image, a negative image, or a mixed output image with negative and positive parts. The characteristics can be changed continuously by adjustment of V_1 and V_2. This enables complete control of image type, gamma and brightness over a wide range.

The performance characteristics shown in Figure 2.6 were obtained with an experimental panel having a 10 micron diameter, tungsten-wire grid wound with a 300 micon spacing. The electroluminescent layer is green ZnS, and the photoconductive layer is CdS. The curves show light output L_2 as a fraction of light input L1 with the amplitude and the phase of power supply voltages V_1 and V_2 as parameters. A constant operating frequency of 800 cycles was used.

Curves A through D are experimental curves for 4 values of V_2, with V_1 held constant at 300 volts. Curves E and F are similar experimental curves for 2 values of V_1, with V_2 held constant at 1,500 volts.



CURVE	V_1	V_2	PHASE
A	300	0	--
B	300	300	SAME
C	300	450	OPPOSITE
D	300	1,500	OPPOSITE
E	0	1,500	--
F	90	1,500	SAME

Figure 2.6 Performance Characteristics

Curve A is for $V_2 = 0$. The photoconductive layer and electroluminescent layer are then effectively in series across the V_1 power supply. The electroluminescent layer is excited with the lateral photoconductive current I_1 ($=I_3$), which increases with intensity of light input L_1. Thus, the panel light output is a positive intensified reproduction of the input image.

Curve B is for V_2 in phase with V_1. Lateral photoconductive current I_1 and the vertical capactive current I_2 are nearly in phase. The amplitude of the total luminescent layer current ($I_3 = I_1 \pm I_2$) increases. Gamma and brightness range decreases because part of the increased I_3 is not under the control of the incident radiation (input light L_1).

Curve C is for V_2 slightly more than 180 degrees out of phase with V_1. The lateral dark current I_1 is opposite in phase to the vertical capacitive current I_2. The structural form of the equivalent circuit is similar to that of a bridge circuit. The vertical capacitive dark current compensates the lateral capacitive dark current I_2, and the dark value of I_3 is greatly decreased.

When light input L_1 is applied, I_1 changes from lateral capacitive dark current to lateral resistive photoconductive current. Its amplitude also increases. This causes a sharp increase in the amplitude of the luminescent layer current $I_3 = I_1 \pm I_2$. The result is positive image intensification with high gamma and large brightness range.

Curve D is for a much larger value of V_2, applied 180 degrees out of phase with V_1. In the region where the input light L_1 is low, I_1 is over-compensated by the excess L_2. In this region, increase in light input L_1 increases I_1 which tends to cancel the excess I_2, and the amplitude of I_3 and dependent L_2 decreases. The light output in this region is a negative intensified reproduction of the input image.

Where L_1 is large enough to completely cancel the excess I_2, and beyond this point, the amplitude of I_3 again becomes directly proportional to L_1. The curve of L_2 as a function of L_1 is thus V shaped. If the input image is relatively dark the output image is the negative of the input. If the input image is adequately bright, the output image will be a mixed negative and positive reproduction.

Curve E is for high V_2 and zero V_1. The electroluminescent layer is effectively in parallel with the photoconductive layer, and in series with the transparent dielectric layer. The layer is excited by the vertical capacitive current L_2 ($=I_3$) that penetrates the photoconductive layer.

As the intensity of L_1 increases, the lateral photoconductivity of the photoconductive layer increases and acts like an electrostatic shield. Current I_2 is bypassed to the parallel grid electrode. With increasing light input, electroluminescent layer current I_3 ($=I_2$) decreases monotonically. Light output decreases similarly. The output image is an intensified reproduction of the input image throughout the entire L_1 region.

Curve F is for high V_2 and much smaller in-phase V_1. When light input is low, the electroluminescent layer is excited mainly by the vertical capacitive current that penetrates through the photoconductive layer. This current decreases with increasing light input. Current L_1 from the photoconductive layer is in phase with current I_2. It adds to I_2 and tends to reduce the rate of decrease of total I_3 with increase in light input L_1. The output image is a negative intensified reproduction of the input image, but gamma is lower and brightness range smaller than when V_1 is zero.

These examples describe performance with V_1 and V_2 of the same or opposite phase. Performance characteristics can also be varied by continuous phase control, and interesting characteristics can be obtained. Performance characteristics may also be varied (and sensitivity improved) by direct current control of the lateral conductivity.

Resolution of the intensified images is higher than that expected from the spacing of the parallel grid electrode, because lateral photoconductivity is used and photoconductive current is not converged.

Experiments which were made to check the resolution of the panels showed that when the incident pattern is perpendicular to the grid the resolution is almost independent of the grid pitch (if the grid pitch is reasonably small) and is mainly dependent on the uniformity of the photoconductive and electroluminescent layers, and on their respective grain sizes. Resolution of over 10 lines/mm is attained in this direction.

When the incident pattern is parallel to the grid the benefits of lateral conductivity are limited by the grid pitch. Resolution is still higher than expected, and falls between the limits of one line/pitch-length minimum and three lines/pitch-length maximum. Isotropy of the resolution can be improved by using a mesh grid electrode instead of a parallel wire electrode.

As a result of discussions [redacted] we find that, without need for further experimentation, there are several significant improvements which can immediately be made in the panel. A finer precision mesh can be used in place of the present hand-wound grid. At the outset of this program, an improved version of the present panel will be built as quickly as possible for evaluation. As the program proceeds subsequent versions will be built, each reflecting the cumulative improvements attained in the previous models.

The research program will be oriented to improve all the parameters of the grid-controlled PC layer, as well as to substitute VARAD for the EL layer.

The image intensifier may be used to intensify greatly enlarged images (100X) from high resolution photographs. If the film has a resolution of 400 line pairs/mm and a magnification of 100X is employed, the final resolution is 4 line pairs/mm and the present EL-PC panel has more than adequate resolution. In practice the resolution has been limited to about one third the control grid wire spacing. Since the present panels use wound grids, a 250 micron spacing has been the best attainable. This can easily be improved through use of an etched grid. In addition, the control grids are wound as parallel structures rather than as meshes and a

2:1 improvement in resolution uniformity can be expected through use of a mesh grid. Appropriate grids are commercially available from Buckbee-Mears and are used in storage tubes. The grids are in the form of metal sheet about 1 mil thick and perforated with square holes, 1000 to the inch. This should give a resolution capability of at least 40 lines/mm.

In subsequent parts of this proposal, we describe how the EL layer is replaced with VARAD. There are other PC approaches, of

STAT course such as the [redacted] approach (described elsewhere in this proposal) that might also be advantageously combined with VARAD and, though we presently favor the [redacted] approach for combination with VARAD, we will continue to examine other approaches and will remain open to pursuing them. STAT

2.5 Alternate PC Approaches

[redacted] is convinced that VARAD is a more promising medium as the output layer of an image intensifier screen than present electroluminescent materials. However, there are numerous advanced photoconductive techniques that are of considerable interest besides the [redacted] grid-controlled layer, and some system techniques.

In addition to the [redacted] where some of the first PC image intensifiers, including the grooved system, were developed, there are a number of other vendors of basic photoconductor powders as well as a number of firms involved in manufacturing photoconductors in large continuous sheets for application to image making. Examples of such firms are [redacted] who is presently utilizing photoconductors in combination with their thermoplastic films for use in data recording and displays; [redacted] who has recently announced a very high resolution photoconductor control layer, and [redacted] which is working on PC-EL storage devices.

Although it is not the intent of this proposal to commit at this point to a particular approach and its associated vendor, we wish to point out that communication with various vendors has taken place and some encouraging results with regard to feasibility of mating a prefabricated photoconductor layer with [redacted] VARAD cell have developed.

Of particular note is the Librascope approach only announced at the Society for Information Display meeting on 26 February 1965. This firm has developed a photoconductor control layer that has the unusually high resolution of .003" spot size without utilizing the more expensive structures such as grooving the photoconductor or using embedded grids. Conversations with both their technical people and production people since learning of this recent development have been encouraging. Although a final decision with regard to feasibility and performance will be one of the subjects to be further developed in the first phase of the proposed program, at this point no insurmountable barriers appear. [redacted] is presently further investigating the feasibility of marrying their approach to our light modulator panel and is presently making special measurements on their photoconductor layer to this end. Another feature of this photoconductor approach is that it is amenable to deposition by silk screen, settling, or vacuum evaporation; furthermore, [redacted] is in the process of tooling up production facilities to turn out a hundred such panels by the end of the year. It might be pointed out, however, that in their original intended application for use with the EL phosphor, they are capable of achieving a brightness which is inadequate for the IIS specification without utilizing the VARAD system.

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Other techniques for image intensification have been reported in the literature but are not sufficiently developed for their characteristics to be meaningfully evaluated. The field will be continually surveyed during the course of this program to determine whether any of these techniques have developed into useable devices. In addition, breadboard PC layers will be constructed at the Information Sciences Center to test other candidate photoconductor material and associated matrices.

2.6 Anticipated performance

As indicated previously, the electrical field strengths exciting the VARAD will be essentially the same as those exciting EL material. Actually, of course, due to the lower voltage requirements on VARAD and its wider choice of operating frequencies, different electrical signals may be applied, and more sensitivity may thus be attained. However, for purposes of an analysis, experimental and theoretical data obtained for the EL-PC [redacted] system can be used in the present analysis if allowance is made for the differences between VARAD and EL material, and if allowance is made for the difference in the visual readout technique.

STAT

The sub-optimum conditions considered below are still, in many cases, far better than the conditions developed for previous EL-PC systems and, in all cases, at least as good. Some indications will be given as to how further improvements may be achieved.

The parameters will be analyzed in the following order:

- Brightness of VARAD versus EL material
- Uniformity of Output Illumination over Screen
- Brightness Distribution Lobe
- Gain
- Resolution
- Life Expectancy
- Color Temperature
- Recovery Time
- Signal to Noise Ratio
- Reflectance

Brightness Levels and Tonal Rendition

Linearity and Gamma

Size

Power Requirements

Contrast Modulation, Image Reversal, Density Expansion and Compression

Monochromatic Sensitivity

This order is selected for convenience in presenting our analysis.

After analyzing the parameters, conclusions will be presented concerning the items listed, including:

a. The relative feasibility of achieving the stated requirements of each of these parameters;

b. Compatibility, relationships, and trade-offs with other parameters;

c. Our technical approach to achieving the design goals of each parameter.

Brightness of VARAD versus EL Material

We will consider first EL material and then VARAD with respect to brightness.

For EL, 220V across a 1 mil thick layer will produce about 130 foot lamberts with commercially available high performance phosphors. For 110 volts, under the same conditions, approximately 42 foot lamberts are obtained, and for 55 volts under the same conditions, approximately 10 foot lamberts. This is roughly linear after a threshold involving negligible brightness for some significant voltage less than 55 volts. We have here a change of roughly 0.73 foot lamberts per volt over the more or less linear range.

A field of 100 to 200V across a 0.001 inch layer of VARAD will produce an electrodichroic ratio of 15. Starting with an optical density, D, of 2, when un-excited, this would lead to a D of 0.125 when excited. Assuming that a field of 200V across a 1 mil layer of VARAD is necessary to produce the change in D from 2 to 0.125 (an assumption on the conservative side with respect to the above figures but one which allows a direct comparison with the EL case) we may compute a corresponding change in the brightness associated with the VARAD screen if we assume various illumination levels for the VARAD. Because of the double pass of light through the VARAD, the effective values of D for the extremes considered are 4 and 0.25. If the VARAD had no reflectance, only absorption, this means that, if the power light input were enough to provide a brightness on the white surface of, say 400 foot lamberts in the absence of the VARAD, it would produce 0.04 foot lamberts with the VARAD un-excited and 224 foot lamberts with the VARAD excited.

Figure 2.7 compares these data for EL material and VARAD. The broken line represents the estimated characteristics of VARAD, and the solid line represents high performance EL material. Use of a higher intensity power light input than the one assumed would lead to higher maximum brightness, for 200 volts excitation, than 224 foot lamberts shown in the figure.

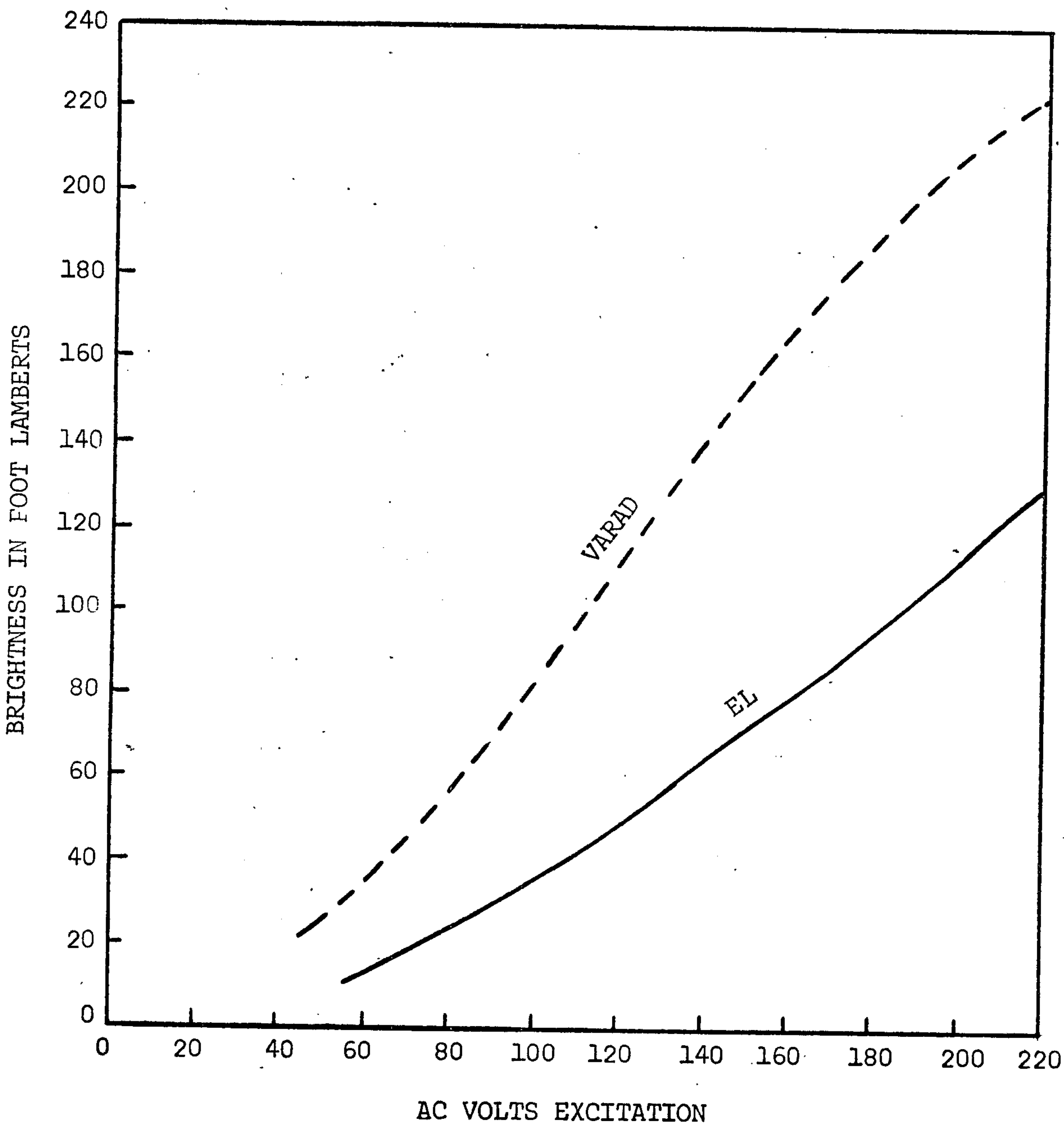


Figure 2.7 Brightness Variations with Voltage

It has been assumed that there is no light reflected or scattered from the VARAD, that is, that the light is absorbed to varying degrees by the VARAD, and reflected only by the white layer behind the VARAD. Any light seen by the observer that is not reflected from the white layer can be kept negligible, using HEA interference films to minimize reflected light. VARAD is effectively a pigment, and like ink on white paper, would maintain contrast in high ambient light. Unlike the case of the EL illumination, the VARAD image would be made brighter by ambient light, like a half-tone magazine illustration or snapshot.

The above numbers assume that the illuminating light for the VARAD screen comes in perpendicular to the plane of the VARAD screen. Figure 2.8 shows how a side-lighted VARAD screen with a 45^{o} viewing angle would permit the light to come onto the screen at an angle of about 30^{o} to the plane of the screen. A screen lighted from the top and bottom is illuminated from a larger angle, as seen in Figure 2.9.

The fact that most of the light may come in at an angle between about 30^{o} and 45^{o} with the plane of the screen and may be viewed at an angle of from 45^{o} to 90^{o} with the plane of the screen, as shown in Figures 2.8 and 2.9 , means that, on the average, the light will pass through about 1.25 to 1.75 mils of VARAD rather than 1 mil for a 1 mil thick layer. This will either reduce the maximum brightness to about 170 foot lamberts, on the average, or require increasing the total illumination of the screen by a factor of about 1.3. It will also slightly increase the picture contrast.

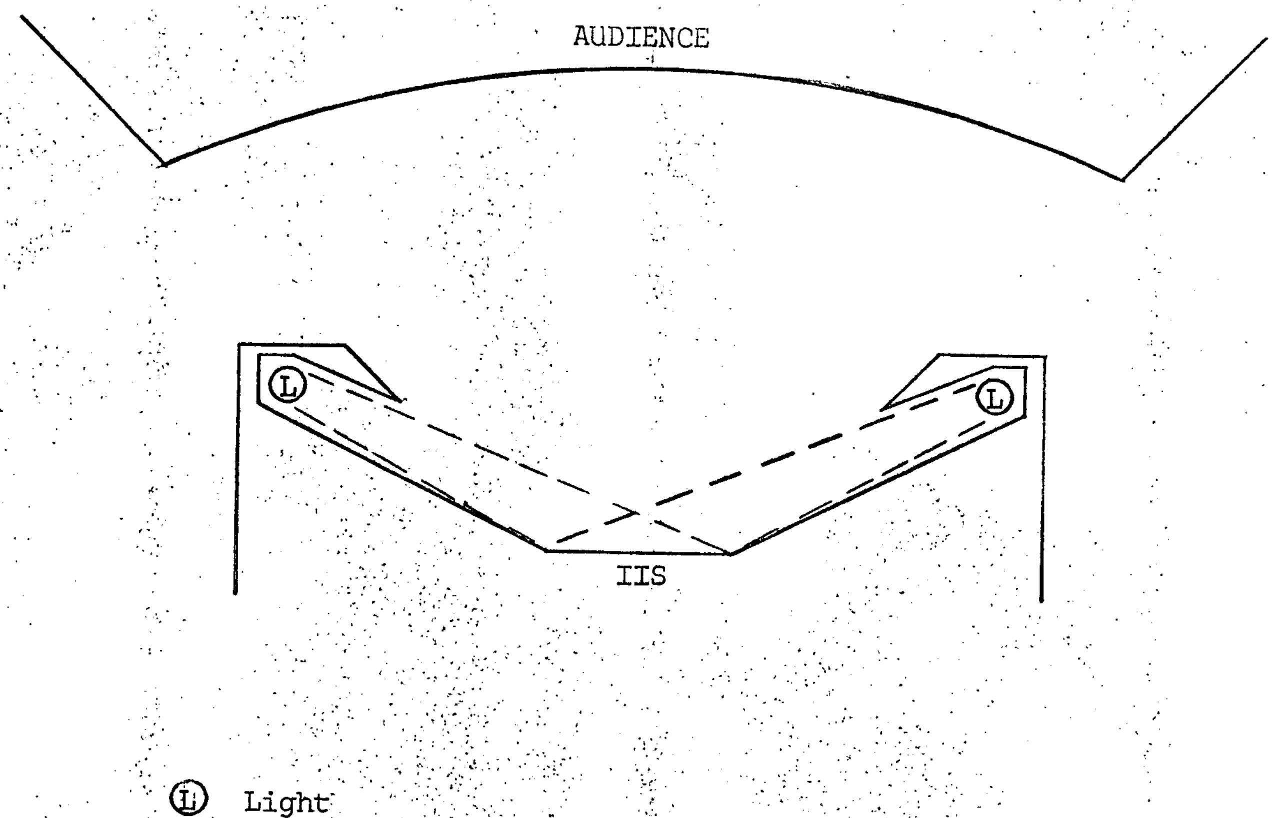


FIGURE 2.8: LIGHTING GEOMETRY FOR IIS TOP VIEW

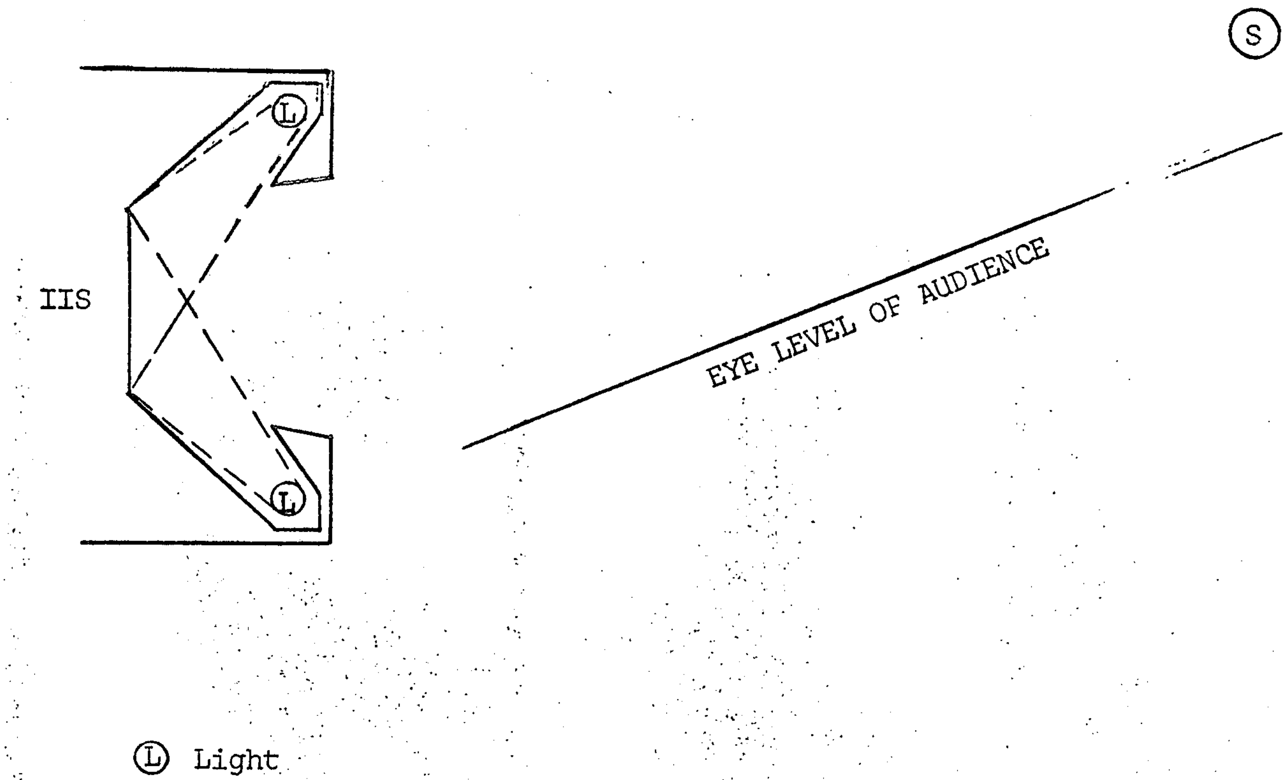


FIGURE 2.9: LIGHTING GEOMETRY FOR IIS SIDE VIEW

It is, of course, not mandatory that the housing for the lights be as large as in Figures 2.8 and 2.9 . An alternative spotlight say at S, in Figure 2.9 , would even more closely approximate a situation where the screen is lighted normal to the image plane, and, in this case, the housing for the lights L would not be provided at all. A smaller housing for the lights with more oblique lighting can also be used with little loss in brightness. The situation represented by Figures 2.8 and 2.9 represents a compromise between the extremes of more oblique lighting and almost normal lighting with a spotlight, and will be used as a basis for further calculations.

It was assumed in comparing VARAD to EL material that the same voltage was available for each. Actually, because of the wider choice of excitation frequency of the VARAD to electrical excitation when compared with EL material, it would be possible, in design optimization to utilize the PC layer more efficiently with VARAD than with EL material. As an example, CdSe photoconductor layers can be made to vary from 10^{12} ohm/square dark to 10^{7} ohm/square at approximately 1 foot-candle. A 3 mil resolution spot on the VARAD layer has a capacitor impedance of 10^{7} ohms at 15 kc, but 10^{8} ohms at 1.5 kc - a good match. Hence, we would expect to be able to deliver more voltage to VARAD than to an EL layer as a result of a given input light level to the PC layer. In this sense, Figure 2.7 represents a conservative comparison of VARAD to EL with respect to gain.

Figures 2.8 and 2.9 may obviously embrace more than the one to four persons viewing the IIS, going beyond the requirements of the RFP in this respect. It may also be seen that because of the anti-reflection coating and lamp design, no glare from the light sources is reflected into the audience.

A vertical viewing angle 45° on either side of the horizontal can easily be achieved as in Figure 2.9 in various ways. One is to have an elevated screen with the side view resembling Figure 2.9, the screen being tilted down slightly. Another way is to use a shallower side view configuration. The spotlight arrangement mentioned above would be another way. Still another way would be to omit the lights shown in Figure 2.9 , keeping the ones shown in Figure 2.8

Uniformity of Output Illumination Over Screen

There are two general factors in the VARAD system that would contribute slightly to non-uniformity of output illumination over the screen as a function of distance from the center of the screen. These are (a) non-uniformity of illumination by lights L in Figures 2.8 and 2.9 , and (b) non-uniformity due to factors influencing the electric field strength that excites the VARAD.

With respect to factor (a), note that the radiant energy from a line-source of light falls off inversely as the distance rather than as the square of the distance, so that at all points on the IIS, one light linearly compensates for changes in illumination from the other light as a function of distance from the lights, to a very good first approximation. Furthermore, any second order variations due to the vertical lights tend to be compensated by the horizontal lights, and vice versa. Note, also, that the incidence angle of the light from any one light source to any point on the IIS does not change very much in Figures 2.8 and 2.9 , nor does the distance from light source to points on the screen change very much. Variation in output illumination over the screen due to factor (a) should thus be entirely negligible.

There should be no electrical reason for non-uniformity of VARAD itself due to factor (b) with proper design. The small edge effects need cause no trouble if the IIS is made slightly larger than the image projected upon it. The transparent conductor layers (tin oxide) can be made low enough in resistance (the order of tens of ohms for thin layers) with respect to the other impedances that there should be no problem on this score. With proper optical design, there should be no optical problem due to factor (b) in projecting the film image on the PC layer. However, obtaining uniformity of sensitivity for large areas of PC still is a problem requiring further development.

Any non-uniformity of output as a function of distance from the center that does occur can be compensated by making the white layer in Figure 2.1 very slightly gray as a function of distance from the center.

Non-uniformities of thickness at randomly located spots or points should be held well within tolerances by proper manufacturing and quality control techniques. The VARAD-PC system would have an advantage, here, over an EL-PC system, because both the EL and PC layers might tend to develop coincident "hot spots" but the VARAD should not; being a continuous liquid film in constant thermal diffusion equilibrium.

With respect to grid shadowing due to grids in the PC layer (if this is the final approach taken), the wound wires or etched conductor paths of the proposed VARAD-PC image intensifier act as charge distributors within the PC layer, and not in any real sense as localizing structures. As has been demonstrated at the New York World Fair exhibit [redacted] even the present widely spaced parallel wire distributors do not contribute significant visible non-homogeneity in the output image at normal brightness levels. A two-dimensional grid-mesh having 1000 lines/inch, which we propose will similarly cause no grid-shadowing of the image and should measureably improve both gain and resolution of the panel, as described in our proposal. (Resolution is almost completely independent of the grid pitch when this pitch is as small as or smaller than the 300 microns of the present [redacted] panel. The much more closely spaced distribution lattices to be used in the proposed new panels are for the purpose of greatly increasing total dynamic range - they are not required for homogeneity of the output image.) The substitution of VARAD for the EL layer in the [redacted] system will not alter this matter.

Brightness Distribution Lobe

Viewing from the side will result in slightly lower intensity and higher contrast, as pointed out above, due to looking through slightly different distances in the VARAD. Within a viewing angle 45^{o} from the normal to the IIS, maximum brightness should not change by more than $\pm$ 10%, but portions of the VARAD that are not very transparent would very possibly undergo a greater change in brightness. We will attempt to improve this situation in the development phase of the program.

Gain

The proposed system can easily exceed a brightness of 50 foot lamberts due to 1 foot candle highlights excitation. As seen in Figure 2.7 , substitution of VARAD for the EL layer increases the gain substantially.

Resolution

The resolution of EL-PCpanels developed by the [redacted] STAT

STAT [redacted]re 10 lines/mm in the Y direction and 4 lines/mm in the X-direction. Discussions with [redacted] STAT of the research institute have verified that the theoretical limitation on resolution is far greater than obtained at present. In fact, the limiting factor at present is the choice of grid structure, which when replaced by a rectangular grid will provide a resolution capability in all directions exceeding the specified 10 lines/mm. The VARAD system that we propose should have at least equal resolution. A contrast of 100:1 will be a design objective that should be achievable with VARAD since scattered light from unexcited VARAD will be reduced to 0.3% by use of HEA multilayer anti-reflection coating and the "black velvet" appearance of VARAD. We anticipate that the transfer function at 10 lines per mm can be at least 90% modulation, 20 lines per mm at 90% MTF will be the design goal.

Life Expectancy

With substitution of the VARAD layer for the EL layer, there is no anticipated life expectancy problem whatever. The system could easily operate at a maximum brightness in excess of 200 foot lamberts for much more than 200 hours with far less than 10% degradation of any performance parameter. The EL layer has been the source of life expectancy problems, and, by substituting VARAD for the EL layer, the problem ceases to exist.

Color Temperature

Any color desired can be used. The color temperature range of 3500° to 5500° is particularly convenient because of the wide choice of sources available.

Response Time

The VARAD layer will normally darken in 10 milliseconds and clear in 10 milliseconds. The normal darkening time can be shortened by providing for an electric field in the plane of the VARAD layer. In terms of photoconductor time constants, the rise and decay times of cadmium selenide type powder-sintered coatings deposited on glass substrates are of the order of 8 milliseconds for rise time to 1/2 maximum current, or decay to 1/10 maximum current. These times increase at 102 illumination level, but can be reduced by infrared or heat quench. Even at the low illumination of 0.1 foot lamberts, it appears that the 0.3 second rise time would not be too critical for step-and-repeat viewing of intensified images in still-picture projection. Rise and decay time of these photoconductive materials can be decreased by an order of magnitude (i.e., to 0.03 and 0.008 second) by presensitization with ambient light. Flash (or steady-state) background light exposure will be investigated in the second phase of development to reduce the time constants of the photoconductive layer to these relatively low values. Infrared quenching of the photoconductive layer could also be used to still further reduce decay time.

Signal-to-Noise Ratio

A modification to the conventional definition of signal-to-noise ratio is needed to make the term meaningful for the Image Intensifier Screen. For uniform illuminance of the Image Intensifier Screen, the entire viewing screen should be of equal brightness with no visible dark areas. The design goal for the Image Intensifier Screen will be a S/N ratio of at least 100 for every square inch. At reasonable illumination levels, "flicker" or "scintillation" noise is negligible. The primary sources of interference in EL-PC systems are to be found in phosphor granularity and blemishes in deposition. Through substitution of VARAD which consists of a suspension in liquid of millions of 1 micron length "needles" and use of precision fabrication techniques to assure uniformity, it is expected that effective S/N ratios of at least 100:1 can be achieved or exceeded.

Reflectance

Unexcited VARAD inherently presents the tone of "black velvet." In addition, reflection minimizing interference films will be used to reduce front surface reflection to 0.3%. The VARAD system will operate in normal room light, or even bright sunlight.

Bright Levels and Tonal Rendition

STAT

The [redacted]ystem exhibited a tonal range of 10 gray shades. The EL layer appeared to be the primary limiting component in the number of gray shades available. We do not yet have full experimental information on the number of gray shades that can be obtained with VARAD, but because of its great dynamic range and freedom from the problems that beset EL material, we feel confident that the proposed system represents a significant improvement over the EL-PC grid-controlled system in terms of the number of brightness levels that can be displayed.

Linearity and Gamma

The linearity characteristics of VARAD have not yet been fully determined. However, there is no reason to expect VARAD to be any less linear in its characteristics than EL material. In fact, due to its wider excitation bandwidth, there should be greater design flexibility in utilizing its most linear operating range or in designing the system so that non-linearities of the VARAD and photoconductor cancel and the overall result is linear operation. In addition, the grid-controlled PC layer can be deliberately designed for non-linearities in order to partially cancel other system non-linearities, within ±10%; gamma can actually be controlled in this way.

By proper selection of power supply amplitude and phase the gamma characteristics can be changed from +1 to -1 thereby producing an exact photographic reversal, hence positive-negative viewing is easily obtained. A wide range of lower and higher contrast ratios may also be achieved, as well as partial reversal, for density contouring.

Size

The thickness and weight-to-area ratio of the IIS that we propose can be made approximately that of a conventional screen. There appears to be no theoretical limitation to screen size. The 12" x 12" screen in question, does not appear to present any serious problems. Fabrication of a 6" x 6" screen to prove feasibility will, upon approval, be followed by fabrication of a 12" x 12" screen meeting design requirements. One of our potential vendors is presently tooling up for a 30" PC deposition chamber.

Power Requirements

The power requirements specified in the RFP can be easily met. The oscillator driving the panel must only supply negligible wattage dissipated in the PC layer, the VARAD layer being reactive rather than resistive. The illuminating lamps will draw an estimated 200 watts to achieve 200 foot lamberts if flourescent lamps are utilized, or 500 watts if tungsten lamps are selected.

Contrast

Controllable contrast modulation is inherent in the proposed system. Complete linear intensity reversal would be available at the option of the operator. Expansion and compression of the brightness range can also be achieved in modifications of the proposed system.

Monochromatic Sensitivity

The monochromatic sensitivity requirement of the RFP can be easily met. Most photoconductors have a fairly broad range of wavelengths in the region of their peak sensitivity, allowing a choice of desired monochromatic exciting light.

Returning, now, to the three questions concerning (a) feasibility, (b) trade-offs, and (c) the technical approach proposed by [redacted] we STAT submit the following:

(a) We believe that it is feasible to achieve all of the requirements of the RFP with respect to each of these parameters listed in the RFP, to achieve the design objectives where noted in the RFP together with minimum design requirements, and in many cases to far exceed the specifications sought in the RFP, using VARAD and either the STAT [redacted] grid-controlled PC layer or some other advanced PC system STAT such as the [redacted] system. Relatively speaking, we believe that the easiest parameter to achieve with the VARAD approach (and the one which goes the farthest beyond EL capabilities) is extremely high brightness with absolutely no sacrifice of lifetime. High gain and color flexibility are other easily achieved advantages, along with increased sensitivity. Also, some image manipulation capability is an inherent property of the PC system proposed without having to put it in ad hoc. The most difficult items may be brightness distribution lobe, linearity, response-time, and uniformity, though we believe that the VARAD system has an advantage over an EL system in most of these respects. We foresee no particular difficulty regarding linearity, but this is the parameter about which we have the least experimental information at this time. Basically, we have more design flexibility than in the case of an EL-PC system, and believe that we can exceed all design specifications.

(b) The major trade-off for the proposed system is sensitivity (or gain) vs. image resolution. This happens for two reasons. The thinner the VARAD layer, the higher is both its resolution and its voltage sensitivity, as it is for EL. However, the effects of stray capacitive coupling causes resolution decrease, just as with EL. Secondly, the inherent sensitivity of thePC layer, using any known approach, must to some extent be traded off for resolution -- whether grid, grooved, or the [redacted] approach is used. This holds true for EL-PC, or any other PC layer approach. However, the significant compatibility relationships are between high brightness, gain, sensitivity, color flexibility, ability to operate in high ambient light, and high life-expectancy as a result of the fact that VARAD modulates light rather than emitting it. Also, limited image manipulation, capability for gamma corrections for linearity, and high gain are complementary properties of the [redacted] PC layer that we favor because it combines high resolution with high sensitivity.

(c) Our technical approach to achieve these design goals is fundamentally based upon (1) replacing the EL layer with VARAD, and (2) combining this with the most advanced PC technique available, along with other applicable techniques such as optical interference films. The technical approach is answered in more detail by the entire body of this proposal.

Figure 2.10 is an artist's conception of an IIS such as we propose.

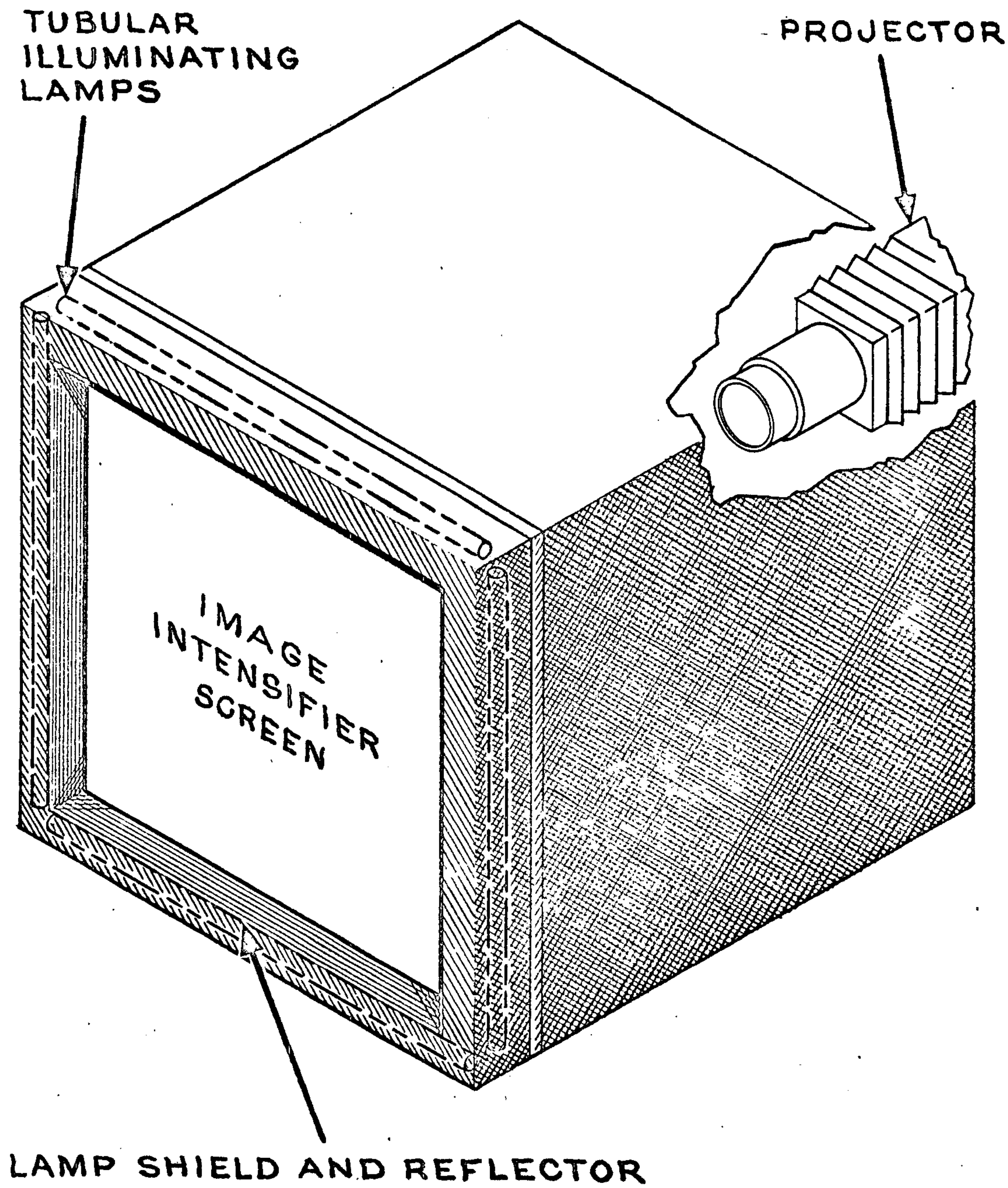


FIGURE 2.10 ARTIST'S CONCEPTION OF IIS

3.0 PROGRAM SCHEDULE AND RELATED INFORMATION

3.1 Schedule

Figure 3.1 depicts the proposed schedule for accomplishing the required analysis, design, fabrication, and test activities leading to the completion of the Image Intensifier Screen program. The delivery of hardware is divided into three phases which are:

a. 6" x 6" Screen - 7 months ARO

b. 12" x 12" Screen - 9 months ARO

c. 30" x 30" Screen - 12 months ARO

The indicated tasks are described in detail in Section 3.3 of this proposal.

3.2 Reports

Although not called out in the proposal, [redacted] STAT

STAT [redacted] feels it would be most advantageous for the customer to receive as much documentation as possible and therefore proposes the following reports be submitted.

In addition to delivery of the three Image Intensifier

STAT Screens, [redacted] will provide a comprehensive report concurrent with each screen. These reports will contain information as to the approach taken, characteristics, and operating parameters. Also, we will submit monthly letter type reports relating progress for the month, any problem areas and contemplated work for the next reporting period.

STAT In addition, [redacted] will supply a final report, one month after delivery of the 30" x 30" screen or thirteen (13) months after receipt of order. This report will encompass the entire project period and will summarize discussions and technical problems and will include overall conclusions derived from the work and any recommendations for future activity that can be determined from the results and conclusions of the program.

3.3 Program - Technical Tasks

During the first period, the following experiments and determinations will be made on the VARAD panels presently in house:

Modify an amplifier to be driven by a variable frequency oscillator with voltage sufficient (up to approximately 300 volts) to completely activate the film panel.

Determine the light transmission as a function of applied voltage.

Determine the spectral light absorption characteristics of the VARAD light panel.

Determine the voltage-current relationships (complex impedance) of the VARAD panel as a function of operating point.

Determine the optical and electrical properties of the VARAD panel as a function of applied electrical frequencies (that is, per cent modulation and electrical loading).

Confirm resistance to fatigue of the panel from application of high intensity light and round-the-clock activation of the cell. Replace liquid if the per cent modulation of light decreases under this test.

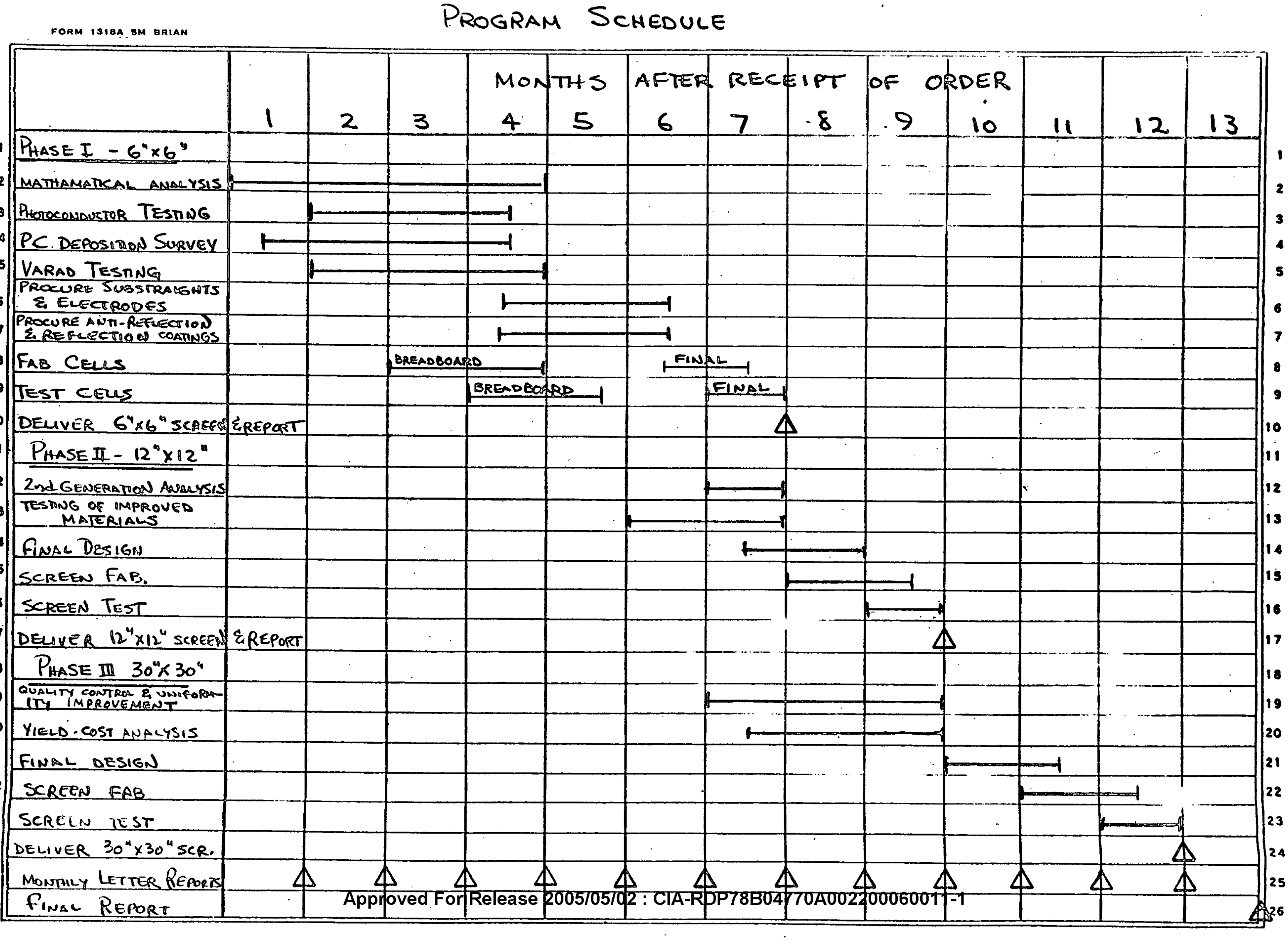
Determine the effects of temperature (high and low) on VARAD panel opening and recovery time as well as on the above mentioned optical and electrical parameters.

Determine the edge sharpness or resolution on the panel that has only 1/2 of a back conductive electrode.

Apply point electrodes to the second cell to demonstrate crude imaging.

Fig. 3.1 IMAGE INTENSIFIER SCEEN

PROGRAM SCHEDULE



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Demonstrate the VARAD panel in the electro-photochromic projector to show modulation and projection under large screen conditions. This will be with no image, only an "off-on" effect in a measurement of dynamic range or contrast at the screen.

Connect various discrete packaged commercial photoconductors in a series circuit with the VARAD cell to simulate a single element photoconductor-VARAD sandwich.

The result of the above work will be to provide a thorough knowledge of the behavior of VARAD, electrically, optically, and as a function of other physical parameters such as light intensity, temperature, electrode spacing, etc. Using this information, a mathematical design study will be performed to determine:

What parameters of the VARAD liquid (such as concentration, viscosity, etc.) should be varied to optimize its performance in a display device.

What parameters of the cell construction should be changed to optimize its performance as a display performance device (such as electrode spacing, optical coatings, dielectric thickness, etc.).

Secondly, the mating of the optimized VARAD panels and their predicted performance will be studied in conjunction with the known properties of the various available photoconductive materials so that optimized photoconductive material can be ordered. The parameters involved include bulk resistivity, binder material, photoconductive film thickness, choice of the photoconductive component, viz., CdS, and CdSe, PbS, etc., mechanical structure such as grooving and electrode configuration. Either the completed photoconductive film or the basic material will be ordered for coating here.

Following these steps, the design of the first 6" x 6" screen will be finalized and orders placed for the selected components. While awaiting delivery of the new materials, experiments will be continued on the commercial package photoconductive device with the original VARAD panel. These experiments will determine response curves for VARAD light transmission versus incident light on the photoconductor most sensitive operating point as a function of bias voltage and bias frequency, power gain when using incident light transmitted through the VARAD cell, dynamic characterisitcs when the incident light on the photoconductor is varied in intensity and apply the knowledge gained to design the optimum VARAD cell-photoconductor type combination for the various intended applications.

The final phase will commence with a careful analysis of all work done to date to determine optimum parameters for the 30" x 30" panel together with cost trade-offs.

Fabrication test of the panel will then proceed as shown in Figure 3.1.

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